THE INSTITUTION OF ENGINEERS, AUSTRALIA

National Historic Engineering Landmark Nomination
COOLGARDIE GOLDFIELDS WATER SUPPLY 1898–1903

ISBN 0 909421 20 X

THE INSTITUTION OF ENGINEERS, AUSTRALIA

NATIONAL HISTORIC ENGINEERING LANDMARK NOMINATION

COOLGARDIE GOLDFIELDS WATER SUPPLY 1898-1903

THE INSTITUTION OF ENGINEERS, AUSTRALIA

NATIONAL HISTORIC ENGINEERING LANDMARK NOMINATION

COOLGARDIE GOLDFIELDS WATER SUPPLY 1898-1903

Submitted by:

June 1986

Western Australia Divison, I.E. (Aust.)
and
Water Authority of Western Australia

Research - R M STRICKLAND, BE, M.I.C.E., M.I.E.(AUST.)

Editing and Compilation - R M STRICKLAND AND A MOULDS, M.I.E.(AUST.)

Members, Engineering Heritage Sub Committee, W.A. Division,

ISBN 0 909421 20 X

Prepared for the Engineering Heritage Sub Committee of the Western Australia Division, I.E.(Aust.); with the assistance of the Water Authority of Western Australia, whose contribution is gratefully acknowledged.

Acknowledgement is also made to the J. S. Battye Library of West Australian History for permission to reprint a number of the photographs included; and to the Institution of Civil Engineers in London for permission to use material from Palmer's paper as published in the Institution Proceedings, 1905

CONTENTS

NATIONAL HISTORIC ENGINEERING LANDMARK NOMINATION

COOLGARDIE GOLDFIELDS WATER SUPPLY

FOREWORD

Western Australia made little progress in the first sixty years following foundation in 1829. In 1881 the population was less than 30,000 persons, yet by 1911 it had increased to 282,000 with the bulk of the population increase being in the Eastern Goldfields area. The stimulus came from gold mining.

Following the granting of Responsible Government in 1890, the future of the colony lay in the hands of the pastoralists in the north, some gold mining in the Murchison, and in the eastern "desert" where a modest gold mining enterprise was being carried out at Southern Cross.

On September 17, 1892 the township of Southern Cross emptied following the news of a rich strike by Bayley and Ford at Fly Flat, (later to become Coolgardie). This first rich field drew prospectors from all over the world and more particularly from the eastern States, to be followed by the strike by Paddy Hannan on June 17, 1893 from which developed one of the richest goldfields of all times centred on the "Golden Mile" between the twin towns of Kalgoorlie and Boulder.

Water had always been a scarce commodity in this arid inland area and its lack took many lives; and typhoid and other epidemics spread. A contemporary account reads "The seriousness of the problem can be gauged by the usual prices paid for water ---- 25 shillings per 1000 gallons when the occasional rains filled the tanks ---- and £4 per 1000 gallons when only water condensed from wells and shafts was available".

By mid 1895, the Government of the day concluded that a large comprehensive scheme would be necessary. A report and recommendation was prepared under the instructions of the Engineer-in-Chief, Mr C Y O'Connor. His report to the Minister discloses a studied effort to examine punctiliously the gamut of alternatives.

O'Connor's occupation of the senior appointment from 1891 had been singularly successful, yet he was already the butt of ignorant and mean criticism. He was to be plagued by enquiries until his tragic end. It was left to posterity to applaud his sound judgement and professionalism.

In the circumstances of the colony - its paucity of development, small population and mounting public debt, - and given the ephemeral nature of mines - O'Connor and his advisers were fully aware of the boldness of the engineering solution they offered. This envisaged works estimated to cost £2.6M (say $160M in present currency) and included a concrete gravity dam 100 feet in height; 324 miles of steel pipeline to deliver 5.6 million gallons per day; and in all 8 steam-driven pump stations with associated reservoirs.

The completion of construction by January 1903, in less than five years and within estimate, speaks for the success of those directing - and the large work force contributing. The speed of construction of the pipeline for instance was remarkable. The project was built when the State lacked tertiary and technical educational facilities; and yet the proponents of the Scheme were meticulous in adopting the latest technology and encouraging innovation.

All cement, steel and machinery were imported from Europe or America, over six weeks by steamer or 90 to 100 days sailing time distant; timber was imported from the United States; pipes were manufactured locally using American and German steel plate, adopting the locking-bar patent of the Australian, Mephan Ferguson. The dam was, on completion, the largest in the Southern hemisphere and the pipeline length unprecedented. The pump duty obtained was a record for pumping engines of the duplex class.

The pipeline construction developed the use of thin walled steel pipes, using the locking bar principal, for water supply to remote areas typical of Australian conditions. A reliable water supply for the mining settlements and the railway ensured permanent settlement in the arid eastern goldfields and the viability of the gold mining industry there. This was the first great boost in the development of Western Australia.

O'Connor's 1896 report had highlighted the benefits of a water service to the towns and the railway on the pipeline route. The main conduit has been reconstructed since, above ground, continuously welded, and enlarged over the years to service abutting wheat and sheep properties. Significant enlargement of the Scheme took place again following World War II, when large areas of agricultural land were supplied with domestic and stock water, and a nickel mining industry was serviced in the Eastern Goldfields. To cope with the duty imposed, the Mundaring Weir has been raised and the pumping stations electrified, along with other substantial improvements. It is noteworthy that when the steam plant was phased out, after 50 years of operation, it was performing to the duty as warranted by the makers. Those engineers involved in the raising of Mundaring Weir in the 1950's were impressed by the quality of the original concrete work, uncovered in the process, and of the iron work. In the raising of the wall the design ensured that the external features of the wall were maintained, so as to preserve this monument to our heritage. So too is No. 1 Pump Station, at the damsite, which has been converted to a public museum.

The City of Kalgoorlie honours the Scheme as its inheritance, with commemorative tablets in its main thoroughfare of Hannen Street. As to Western Australians generally, the work is enshrined in the history of the State.

H.E. HUNT BE, FIE(Aust)

1 - EVENTS LEADING UP TO CONSTRUCTION *

The genesis of a public work of the magnitude and importance of the Coolgardie Water Supply is easy to chronicle. Western Australia astonished the world when she launched the bold scheme to pump water from the coastal districts a distance of 353 miles inland. It is a work of hydraulics which has no parallel, and, great as has been the responsibility undertaken by the high officers of State in committing the people to its cost, there is to-day, on the eve of its successful opening, every reasonable hope of it not only being a monument to the brain that conceived and originated the plans upon which it has been constructed, but there will be given to an energetic and hopeful people a service that will more than pay for itself.

What the Asscuan Barrage on the River Nile is to Lower Egypt, the Coolgardie water-pipe is to 40 000 people on the Eastern Goldfields, and the great gold-yielding mines which have turned out over 200 tons of gold, worth, say, £20 000 000.

In the summer of 1893-94 there had been such a rush of people to the goldfields, in consequence of marvellous developments at Coolgardie and the vicinity - and the rainfall that year was so much more scanty than it usually is- that a dire need arose to supply human consumption, quite apart from the demand for the mines and for livestock. Extension of the railway system beyond Southern Cross, towards the new Eldorado, accentuated the necessity for a greater and surer water supply than rain catchment and condensing. It was only by the exercise of energetic measures and the expenditure of very large sums of money that the Government, in supplying alleviating works of a temporary character, averted what would have proved a great calamity for the goldfields people.

The question forced itself upon the attention of the Administration of Sir John Forrest, and the experts of the Public Works Department were engaged in the latter part of 1894 and the early portion of the following year, in obtaining data for an adequate and permanent supply. The Government were at this time thus earnestly considering how the difficulty could be overcome. Then occurred the astounding but practicable proposal to pump water from the Darling Ranges inland through a veritable desert.

The Coolgardie Water Scheme, in its originality and object, is a masterpiece. The cynic aforesaid dismisses the work of great brains, manual labour, and skilled mechanism somewhat in this fashion: "When you can surpass them, you will have something to boast of."

**Extracts from an article appearing in "The West Australian", January 23, 1903.*

It will be long before there is an irrigation reservoir of greater capacity than Lake Moeris, in Egypt, which accepting the figures of an eminent engineer, Sir R H Brown, R.E., held 11 800 million tons of water, or roughly speaking 2 643 200 million gallons, between high and low level marks. The Helena Vale Reservoir has a capacity for impounding power of 4 619 million gallons after due allowance for evaporation, soakage, etc. The goldfields in the Eastern districts, therefore, are assured of a supply throughout the year equal to five million gallons every 24 hours.

The pipeline from the Helena Reservoir to Kalgoorlie used 90 000 tons of steel, which was manufactured into pipes in the State; a most valuable consideration when the employment of local labour is considered by those who have pledged the country's credit for the safety and success of the scheme.

RIVER PROPOSALS

There were many proposals put forward to pump water from the coast. In December 1894, Mr Jobson, a Government water supply official on the goldfields, made a report in regard to the necessity for a supply beyond what the condensing plants could give.

It was in the middle of 1895, that Sir John Forrest asked Mr C. Y. O'Connor to prepare data for a sheme to pump water from a reservoir at the Darling Ranges. Seventeen valleys in the Darling Ranges were examined, after which it was advised by the engineer that the Helena Valley offered the best site and catchment. In April, 1896 Mr W. R. Wilson, a Melbourne capitalist, who had had experience in waterworks at Broken Hill, addressed a proposal to the Government, to bring water to Kalgoorlie and Coolgardie from a catchment 90 miles north of Menzies.

Another feature of the want of water and one that helped to decide the Government upon its course of action, was the opinion expressed that artesian water obtained by boring, would never strike a supply above a trickle, to respond to the demand that would be made upon such a source. Boring to a depth of 3 000 feet at Coolgardie, demonstrated the truth of the opinion.

THE GOVERNMENT'S PROPOSAL

In the Governor's speech, at the opening of Parliament, on July 7, 1896, the Government's intentions were first announced It was stated that a proposal would be placed before the Legislature to supply water by pumping to the summit of Mount Burges, near Coolgardie, from a reservoir in the Darling Ranges at an estimated cost of £2 500 000, for a supply of five million gallons per diem. On July 17, 1896, the general report of the Engineer-in-Chief was completed, and was presented in Parliament, on the introduction of the Bill authorising the raising of a loan of £2 500 000 for this scheme, that being the sum estimated by Mr. O'Connor to complete the work.

Mr O'Connor, in his report to Parliament on the Loan Bill authorisation for the scheme, dwelt clearly and exhaustively upon the artesian bores aspect of this question. Quoted the observations of eminent authorities on bores in Queensland and plainly showed that as the summit of Mount Burges was only 2 500 feet above sea level water could be carried at easy stages of 300 feet by the pumping stations "en route" to the fields. The Helena Reservoir, in his opinion was the only proposal capable of being applied to meet an extremely difficult problem.

Inside and without the Houses of Parliament, the proposed water supply was described by some people as a maniacal project. The answer to that criticism was the opinion of many competent engineers, who considered the work a practicable one.

A STUPENDOUS PROPOSAL

How stupendous seemed the scheme when it was launched will be gathered from the fact that the population of Western Australia was only 12 000, and the State's public debt was £4.5 million. The proposal was to spend upon a single work a sum equal to more than half of the loans then raised, increasing the debt to £7 million. The population has almost doubled during the progress and completion of the scheme, and the public indebtedness had gone up to £15 million.

Another bearing upon the usefulness of the work was the benefit that would accrue to that long stretch of country between Northam and Coolgardie as the greater portion of the land in the vicinity of the railway and pipe track should attract settlement.The motion adopted on October 10, 1894, by the Legislative Assembly , on the initiative of Mr C. Harper, member for Beverley, when the House affirmed its opposition to private speculations exploiting the scheme, was referred to by the Premier, as evidence of the will of members, the Legislature declining to hand over a great national work to a private company.

Another remarkable circumstance on the fields was, that so long as miners were deprived of an adequate water supply for domestic use, they refused to bring their wives and families from the Eastern States.

On August 4, 1896, the Premier laid on the table of the House a memorandum by the Engineer-in-Chief which was read. But Mr O'Connor in his document, declined to disclose the names of the engineers who had advised him upon the pumping scheme, as it was considered improper, for those gentlemen, if consulted publicly, would be entitled to receive their fees. Further, he said, written reports and opinions from English engineers could

be obtained, if the proper times were allowed. Mr Simpson, in criticising the proposed work, urged the obtaining of well-founded expert opinion outside the State engineers. The cost, according to the member for Geraldton, was a mere bagatelle compared with the importance of the scheme. He instanced the lack of public enthusiasm at Kalgoorlie, over the work proposed, but he admitted that a public meeting was held in favour of the scheme.

Mr C J Moran, the member for Yilgarn, ably and adequately championed the cause of the goldfields people. The amendment was negatived on the voices, and the motion was adopted unanimously without the House going to a division. On August 6, a motion by Mr C. Harper, to refer the Bill to a Joint Committee of the two Houses of Parliament was negatived, twelve votes to seven.

In the Upper House the Bill was entered for the first reading on August 12. The second reading was moved the following day by Sir Edward Wittenoom, Minister for Mines, and a long debate ensuing, it was carried on September 2. A proposal to refer the Bill to a Select Committee was defeated, and on September 3 the measure passed through the remaining stages.

The goldfields people busy and feverishly excited over the Kalgoorlie and Coolgardie developments, had no time to think it over except to take it for granted that Sir John Forrest was pledged to give them water, that was all sufficient. As a whole the people of the goldfields, however, gave no assistance to the project. On the contrary it may be said a very hostile spirit prevailed. On the Loan Estimates for 1896-7 a sum of £290 000 exclusive of departmental charges was provided; but, as the work in connection with the enterprise was chiefly departmental, the only money actually expended for construction purposes was a trifle from the allocation for reservoirs. Early in August 1896 in reply to statements uttered in Parliament doubting the quantitiy of water required by the goldfields, Messrs Bainbridge, Seymour and Co. wrote offering to take 5 000 000 gallons per day at 3s.6d per thousand gallons for twenty years, provided the Government would not compete with them in price. At this point plans were prepared for submission to and consideration of a Commission of Engineers in England that it was proposed should be appointed in accordance with paragraph 56 of the Engineer-in-Chief's report that had been placed before Parliament. It was decided that the Engineer-in-Chief should, if possible, proceed to England at an early date to confer with the Commission in regard to the general details of the work, and to be able to give them advice on any local questions that might arise. In December 1896 a cablegram was received from the Agent-General stating that he proposed with the sanction of the Government to appoint Mr Carruthers, the Consulting Engineer for the colony, together

with Professor Unwin (a great authority on transmission of power) and Mr G. F. Deakin the engineer of the Liverpool Water Supply as a committee to consider the Coolgardie Water Supply with authority to appoint another Commissioner if necessary. On the 31st December, 1896 the Government signified its approval of these appointments by cable.

MR O'CONNOR'S VISIT TO ENGLAND

On January 22nd, 1897, after all preliminary investigations had been completed, the Engineer-in-Chief left Western Australia for London arriving there on the 25th February. Mr O'Connor was constantly present at the deliberations of the Commission and with them visited many manufacturing centres and industries in connection with appliances, materials and machinery that might be required for the carrying out of the great project.

With other members of the Commission, Mr O'Connor proceeded to Paris to inspect some patent steel and cement ("Sidero-cement") pipes manufactured by M Jean Bordenave, largely used in Paris for sewerage works, and had been suggested for the Coolgardie pipe-line. On August 3, the Commissioners presented an interim report, and a few days later - August 14- Mr O'Connor left England on his return journey to Western Australia, visiting Krupp's Steel Works, at Essen and Magdeburg, Germany, together with other steel foundries and manufacturies in Europe.

Upon Mr O'Connor's return, work was slowed down in consequence of large outgoings from loan funds on large public works in hand, and a difficulty which arose in placing loans satisfactorily. For that reason it was decided not to press too quickly the Coolgardie Water Supply proposals. Otherwise, the pipes contract could have been let in England in August, 1897. The Governor's Speech at the opening of Parliament, in October 1897, contained the following paragraph: "My Ministers regret that, owing to the large works already in progress from loan funds, which it is impossible to interfere with, some little delay must occur before this great work (the Coolgardie Water Scheme) can be undertaken; but while regretting the necessity for so great an expenditure on this work, they are more than ever convinced that no other means are available for providing a certain cheap, and good supply of pure water for the Coolgardie goldfields". From that day forward, up to within a few months of the completion, the scheme generally became the subject of considerable criticism in a section of the Press.

In May 1898, M.Burgigli was informed by the Premier that the Government were not prepared to accept his offer, as they intended to proceed with the work forthwith themselves, and that, besides that, it would be impossible for the Government

to enter into treaty with any private individual for the carrying out of so large work of the kind, except with the special approval of Parliament.

THE TENDERS FOR THE PIPES

Early in 1898 the final report of the English Commission was received, and in January of that year the Government gave instructions for tenders to be called for the supply of pipes. During the time that the specifications for pipes were being considered Mr Ferguson's patent locking-bar pipe (which had in rather an imperfect state been already considered by the Commission of English Engineers, who were always favourably disposed towards it) was perfected and designed, and again brought under the notice of the Engineer-in-Chief. Simultaneously with the cable for tenders to pipe manufacturers in the British Isles, a similar cable was sent authorising the Agent-General to call for tenders for pumps, the power of the pumps to be as recommended by the Commissioners.

During the early part of 1898 not much actual work was done in the State in connection with the scheme; but the railway line between Mundaring Station and the Helena Weir site was commenced in January and completed in August and the excavations for the foundations of the Helena Weir were started in April. On the 23rd August, tenders for pipes were received in Perth and on the same day a cablegram from the Agent-General quoted the tenders received in London. The Engineer-in-Chief on 3rd September, reported to the Government generally in reference to the tenders received that the lowest tenders received in England were from Messrs Buchner Blageo and Co of Portland U.S.A. for 246.75 miles of riveted pipes and from Messrs Piggott and Co (with Stuart and Menzies) for 81.25 miles of welded pipe (for which tenders had been called) making in all 328 miles of pipe at a total cost of £1 255 308. The lowest tenders received in Perth were for the riveted pipes as above-mentioned from Messrs G & C Hoskins, of Sydney, and (in lieu of the welded pipes) for pipes of the locking-bar type from Mr Mephan Ferguson, making a total of £922 694. In view of Messrs Hoskins and Ferguson both being Australian firms, their tenders, together being lower than the others received and also as the Engineer-in-Chief considered it would be advisable to adopt for the whole main, pipes of the locking-bar type and that type of pipe being considered distinctly better than riveted pipes, it was suggested that Messrs Hoskins and Ferguson be asked, if possible, to coalese and to submit a joint tender for the whole.

After a considerable amount of negotiation, and a fresh contract being drawn in the State, on the basis of the ones prepared in England, the coalition was agreed upon. The Government acquired the patent rights of Mr Ferguson, with the right to manufacture the pipes, and arranged a contract for the supply of half of the total quantity required, with each of the two firms. Before, however, the tenders were actually accepted a notice of motion was tabled by Mr Holmes, in the Legislative Assembly, discussed on September 14 that no tenders for the supply of pipes be accepted without the approval of the House. During the lengthy debate that ensued thereon, Mr Morgans moved an amendment, practically to strike out the whole of the motion, and to insert, "That it is advisable, in the interest of the colony, that the Coolgardie Goldfields Water Supply Scheme should be proceeded with at once, and this House urges the Government to do all things necessary to expedite the work." The amendment was carried after debate. Mr Walter James proposed a further amendment, to be added to Mr Morgans's amendment as follows:- "And to provide that such works, as far as possible, be carried out by day labour, employed on the eight hours system." That amendment was, however, lost. The two contracts, each for half of the supply of pipes were signed by the contractors Messrs G. and C. Hoskins and Mr Mephan Ferguson, on October 18, 1898, the contract price for the pipes totalling £1 025 124. The supply of joint rings was also included in the contracts at a schedule rate of one pound two and sixpence in addition to the price for pipes. The tenders for the locking-bar pipes were some £230 000 less than riveted pipes the same thickness, and it was possible, therefore, with the locking-bar pipes to give an extra one-sixteenth of an inch, and thus ensure more economical maintenance.

THE CONSTRUCTION BILL

On September 20, 1898, the Goldfields Water Supply Construction Bill was introduced by the Premier in the Legislative Assembly, and read a first time. The Bill passed its second reading in the Assembly on September 29, and was read a third time on October 4. The only amendment that was made in Committee of any importance was that any claim for compensation for damage done in connection with the work, unless settled by agreement, should be referred to a Court of Arbitration, consisting of a Joint Select Committee of both Houses of Parliament. The Legislative Council altered that provision and amended the Bill so that the clause relating to compensation read that three Judges of the Supreme Court, sitting without a jury, were to assess the damages, in lieu of the Joint Select Committee of Parliament previously passed by the Assembly.

The tender of Messrs. James Simpson, for Worthington pumps, was accepted. During 1899, active preparations were pursued at Helena Weir. In June of 1899, Messrs Couston and Finlayson made an offer to

supply patent caulking appliances, which they had invented, to caulk by machine instead of by hand. After considerable negotiations had been carried on, and improvements to the machines made by the patentees, in April, 1900, Messrs Couston and Finlayson made a definite offer to sell their patent rights of the machine to the Government, and finally, in August, the purchase of the patent rights was arranged for the sum of £7 500 and also for the supply of a number of caulking machines, together with the necessary oil engines, etc. Early in 1902 a proposal was made by Messrs Couston and Finlayson to complete the work of laying and jointing by contract. Mr C. H. Rason, Minister for Works, submitted the proposals to the Legislative Assembly on January 22. The proposals caused a lengthy discussion, and the member for Beverley (Mr Harper) moved that the matter be referred to a Select Committee.

SELECT COMMITTEE AND ROYAL COMMISSION

The motion was carried, and on the 17th February an interim report was presented in order that the investigation should be continued, a Royal Commission was appointed on 26th February, consisting of Mr Harper, Mr Nanson, Mr Daglish, Mr George Lefroy and Mr W Atkins. Simultaneously with the discussion of the caulking contract in the Assembly a motion was moved by the late Mr Crowder, in the Upper House that the Government should call on the Works Department to concentrate their energies on the completion of the first section of the pipe line of the Coolgardie Water Scheme with a view of providing a test of the working conditions before the prorogation of Parliament.

The scope of the Royal Commission was somewhat extended in order that a thorough inquiry should be made into the whole undertaking.

POST SCRIPT

The uncertainty as to whether economy was being exercised by the Public Works Department provoked most ungenerous and unjustifiable attacks in a section of the Press, upon the Engineer-in-Chief and his assistants. Mr O'Connor's death came just as the work was emerging from a cloud of difficulties. His last written message contained the words "The Coolgardie Scheme is all right." The truthfulness of that statement has been fulfilled. Mr O'Connor advised the Government in his last message to get a good man to carry on the work implying apparently that an eminent engineer from abroad should be appointed, but the Minister for Works appointed Mr O'Connor's subordinate, Mr C. R. S. Palmer, an engineer of considerable attainments and experience in hydraulics to the Government of India, to finish what had been so ably commenced and in great part completed.

One result of the Commission was the marvellous progress of the pipelaying, for in 1902 346 miles of pipe had been distributed, practically the whole of the trench excavated and 324 miles of pipes laid and joined.

Pumping started at No. 1 station on March 31, 1902, the water reached Northam on April 18, Cunderdin on April 22, Merridin on August 22, Yerbillon on September 30, Southern Cross on October30, Ghooli a few days later, Gilgai on December 21, Coolgardie on December 22, and Kalgoorlie on January 16.

2 - DESCRIPTION OF THE WORKS *

Before proceeding to describe in this Paper the design and construction of the works undertaken for the water-supply of the Coolgardie district of Western Australia, it is necessary to touch briefly upon the history and topography of the district.

Since the discovery of the great inland goldfields of Coolgardie in 1892, the career of the State of Western Australia, which previously had made but slow progress, has been uniformly successful; for the resulting mining population created a profitable market for the agricultural and pastoral produce of the well-watered coastal country, which was therefore rapidly settled on as railway facilities were afforded. The town of Coolgardie is situated about 350 miles from the west coast and about 259 miles from the south coast; and, although along the sea-shore and for a considerable distance inland this part of Australia is well watered, the portion - say, 300 miles by 250 miles - of the elevated tableland in the interior of which Coolgardie may be regarded as the centre is among the driest of the countries of the globe, the rainfall having been as little as 3 1/2 inches in a year. Moreover, the surface soil generally is very porous and so excessively saline that, except in rock-holes after rain, really fresh natural water is practically unknown, although repeated boring has proved the existence here and there underground of small quantities of fairly potable water.

About £400,000 has been spent on smaller waterworks of every description, the exceeding dryness of the climate being soon made manifest by the poor result of each small but costly work carried out. It was thus proved that for any large supply of fresh water a source should be searched for elsewhere than on the surface or in the subsoil of any portion of this tableland.

The seriousness of the problem can be gauged by the usual prices paid for water in later days. Even after completion of these smaller works, the prices were:- 25s. per 1,000 gallons when the occasional rains filled the tanks which formed one class of the works, and £4 per 1,000 gallons when only water condensed from the extremely salt fluid obtained in wells and shafts was available.

* *Taken from "Coolgardie Water Supply" by Charles Stuart Russell Palmer, MICE - (Paper No. 3516 - March 28, 1905) THE INSTITUTION OF CIVIL ENGINEERS, Proceedings.*

Yielding to the pressure of popular opinion, the Government spent several thousand pounds without result, in a bore-hole more than 3,000 feet deep in solid granite; various schemes for condensing on a very large scale, at the salt lakes situated in the goldfields, were abandoned on proof of the excessive salinity of the water of the lakes, the difficulty and cost of obtaining a sufficient supply of even this water, and the high price of fuel; and then two proposals for conservation, with sources comparatively near to the goldfields, were considered but abandoned, as the low rainfall rendered it more than questionable whether the yield would be sufficient. By a process of elimination, therefore, there was reached the accepted solution of the problem, namely, a source in the Darling Ranges bordering the well-watered west coast. This scheme had the additional advantage that all intermediate townships, as well as the adjacent Government railway, could be supplied from the main conduit, the railway being especially benefited in its course through about 250 miles of arid country wherein railway water-supply was known to have cost as much as £60,000 in a single year.

By the middle of 1895 the Government of Western Australia had decided that some large comprehensive scheme would be necessary; and, orders for report and recommendation having been issued, there were prepared, under the instructions of the late Mr. C.Y. O'Connor, C.M.G., M. Inst. C.E., the Author's late chief and predecessor in the position of Engineer-in-Chief of the State, thirty-one alternative proposals, from which, after study, three were chosen to be placed before the Government. The source of supply in each case was to be an impounding-reservoir in the Darling Ranges, whence the water was to be pumped in successive lifts to Mount Burgess, north of Coolgardie: thence it was to be reticulated to the various mining-centres, of which Coolgardie was one. In Mr. O'Connor's Report, (Appendix) the three schemes were stated, for comparative purposes, to be as follows:-

"The result of ... calculations went to show (as for steel pipes, that, for one million gallons daily, the cost would be from, say, £700,000 to £1,000,000 (depending on the size of the pipe), and with the cost of delivery varying from 5s. 6d. to 8s. 6d. per 1,000 gallons; while, for five million gallons daily the cost varied from, say £2,200,000 to £2,700,000 (depending similarly upon the size of the pipe), with cost of delivery varying from 3s. 5d. to 6s. 7d. per 1,000 gallons; and that, for ten million gallons daily, the cost varied from, say, £3,500,000 to £4,600,000 (depending similarly on the size of the pipe), with cost of delivery varying from 3s. to 5s. per 1,000 gallons".

The scheme adopted was for a daily supply of 5 million gallons, at a probably capital cost of £2,500,000, and a selling-price of 3s. 6d. per 1,000 gallons, after allowing for interest and depreciation. The consumption of the water provided by this

scheme, which is still in its infancy, has not yet amounted to more than one-fourth of the quantity allowed for; and the Author reported to the Government, soon after becoming responsible, that until much greater development of mining occurs, the consumption is not likely to exceed one-half of that allowed for. It is therefore due to those originally responsible to point out that when the proposals were inaugurated, and, in fact, up to the time when the works were opened, no information and no authoritative opinion outside the Public Works Department could be obtained as to the probable consumption; while, on the other hand, there were the greatest expectations in the public mind of more extensive working of low-grade mines, when comparatively cheap water should be available. These expectations were not confined to the general public; for, some doubts having been expressed in Parliament as to the probability of so much as 5,000,000 gallons being used daily on the goldfields, a well-known firm offered to take that quantity daily for 20 years at 3s. 6d. per 1,000 gallons, provided that the Government would not compete with them in price. In September, 1896, Parliament sanctioned the raising of a loan of £2,500,000 for the construction of a storage-reservoir of about 5,000 million gallons capacity, a 30-inch line of steel main throughout, and a series of eight pumping-stations, with the necessary receiving-tanks and distributing-reservoirs.

In January, 1897, a Commission of English engineers - consisting of Mr. John Carruthers (the Consulting Engineer for the State, in London), Dr. George F. Deacon and Professor W.C. Unwin - was appointed to inquire into and make recommendations as to the kind, thickness and size of pipe to be employed; whether it should be placed above or below ground; and the number, positions and power of the pumping-stations and engines, and the pumping and break-pressure reservoirs. Mr. O'Connor, who was then Engineer-in-Chief to the State, personally placed all available information before the Commission, which issued two reports. (Appendix) In the first or interim report nine pumping-stations were recommended. In the final report the Commission submitted an alternative arrangement, with eight pumping-stations in lieu of nine; and in the adopted scheme the locations of the pumping-stations differ but slightly from those of the first eight stations proposed by the Commission in their interim report: but it was possible to omit the ninth pumping-station, as it was decided to deliver the water into a large service-reservoir at R.L. 1630, near Bulla Bulling instead of on a high hill near Coolgardie, and to increase the lift at each of the last four stations by such small amount as would enable this to be accomplished.

The detailed description of the works will be divided under the following heads:-

I. The storage-reservoir.
II. Construction of the weir.
III. The pipe-line.
IV. The pumping-machinery.
V. The pumping and service-reservoirs, reticulation, etc.
VI. Cost of the works.

The following general outline is given here to facilitate a clearer understanding of the details.

General Outline of Scheme - A daily supply of 5,600,000 gallons was provided for, of which 5,000,000 gallons was for use in the goldfields, and the balance for waste and consumption en route. The supply is obtained from an artificial reservoir, having a capacity of 4,600 million gallons. From this reservoir the water is pumped through a steel conduit, 30 inches in diameter, by a series of eight pumping installations, to the main distributing reservoir at Bulla Bulling, 308 miles from the main storage reservoir and 1,290 feet above the lowest outlet-level of the latter. From the Bulla Bulling distributing-reservoir the water gravitates for 21 miles to the Coolgardie service-reservoir, and thence to the Kalgoorlie service-reservoir, a further 23 1/2 miles, the total length of the conduit from the supply reservoir being 351 1/2 miles.

The first pumping station is located on the right bank of the Helena River and 650 feet down-stream of the storage-reservoir. The pumps draw their water from a stand-pipe 4 feet in diameter, which is placed immediately in front of them and is fed by a 30-inch steel main, which, beginning at the outer valve-house passes under the boiler-house before entering the stand-pipe. The pumps here lift the water a net height of 415 feet, through 1 1/2 mile of pipe, and deliver it into a concrete receiving-tank having a capacity of 468,000 gallons and a depth of 15 feet of water.

The pumps at Station No. 2 draw their water from this receiving tank, the maximum suction-lift being 11 1/2 feet, and deliver it into a concrete regulating-tank at Baker's Hill, 22 1/4 miles from Station No. 2, the net lift being 340 feet. From the Baker's Hill regulating-tank, which is 15 feet deep and has a capacity of 500,000 gallons, the water gravitates to the West Northam regulating-tank, 12 miles distant. This tank is similar in construction to that at Baker's Hill, having the same capacity and depth.

The net fall is 94 feet from Baker's Hill to West Northam, whence the water gravitates to the Cunderdin reservoir, a further 41 miles, thus making a total length of 75 1/4 miles between Stations 2 and 3. The Cunderdin reservoir has an

available capacity of 10 million gallons. No. 3 pumping-station is located about 3/4 mile from this reservoir, and the pumps draw their water from a stand-pipe, similarly to those at No. 1. The section between Stations Nos. 3 and 4 is 62 3/4 miles in length, the net lift at No. 3 being 215 feet. The water is delivered into a circular concrete tank at No. 4, having a capacity of 1 million gallons and a depth of 15 feet. From Station No. 4 the water is lifted a net height of 333 feet, and delivered through a section 32 1/2 miles long into a rectangular concrete receiving tank 20 feet deep, with a capacity of 1 million gallons. At Stations Nos. 5, 6, 7 and 8, the arrangements are similar to those at Station No. 4, and the receiving tanks at Nos. 6, 7 and 8 are similar in design to that of No. 5, having also the same capacity and depth. The net lifts at Stations Nos. 5, 6, 7 and 8 are respectively 52 feet, 106 feet, 56 feet and 183 feet, and the corresponding lengths of section 46 miles, 31 3/4 miles, 45 miles and 12 1/4 miles. From Station No. 8 the water is delivered into a main service reservoir at Bulla Bulling, of 12 million gallons capacity. Thence the water gravitates to Coolgardie, and from Coolgardie to Kalgoorlie. These towns are provided with circular concrete service reservoirs, that at Coolgardie having a capacity of 1 million gallons and that at Kalgoorlie of 2 million gallons.

Early in 1898 the first work on the scheme, namely, construction of the branch line of railway to the weir, was put in hand, and was completed in the following August. In April of the same year, excavation for the foundations of the weir was started; concreting was begun in February, 1900, the first pumping took place in April, 1902, and the weir and subsidiary works were practically finished in April, 1903.

Contracts for the pipes were let in October, 1898, and for the pumps in March, 1900. The excavation of the pipe-trench was begun in March, 1900. The laying and jointing of the pipes was begun in March, 1901; about 90 miles were completed that year and the remaining 260 miles (including the extension to Kalgoorlie) in 1902. The water reached Kalgoorlie in the middle of January, 1903, and the works were formally opened on the 26th of that month. The whole period of construction had thus been less than 5 years, although it was necessary to import all material for construction of the pipes, cement, valves and specials, lead for jointing, pumping machinery, the iron work in the weir, and much other material.

I. - THE STORAGE-RESERVOIR.

When the scheme was first propounded, and, in fact, until shortly before the construction of the weir was begun, there were no river-gaugings available: consequently, in judging of the probably inflow into a reservoir, it was necessary to base calculations on results obtained in other countries. About 3,000 square miles of the Darling Ranges having been examined, and thirteen possible sites surveyed in a preliminary manner, it was finally decided to place the reservoir at Mundaring on the Helena River, where the cost of construction per million gallons of storage would be least.

The rainfall for the year 1902 may be taken as typical of the rainfall generally. During that year the total rainfall, as recorded at the Helena weir, amounted to 27 1/2 inches, the total number of rainy days being 81; i.e., the average precipitation per rainy day was only 0.34 inch. The maximum rainfall in any one day was 1.41 inch.

The unusual variations in the yield are due, in the Author's opinion, to two other causes, whose effects in new countries where records are scanty require much experience and consideration for their correct estimation. The first is that the rainfalls of York and Mundaring, which are all that are available, require to be greatly discounted, owing to a rapid rise of the country for several miles inland from Mundaring, and then a fall to the tableland of the interior; and it is therefore probable that the rainfall on the reverse slope of the Darling Ranges, and on much of the tableland adjoining, is less even than that at York. The second cause is that on the tableland, where the rainfall is smaller and the country is more absorptive than on the ranges, a large and more or less definite amount should be deducted from the rainfall before any estimate of the off-flow can be made.

It was early evident that much of this difficulty would be obviated by placing the weir lower down the river, and thus including a larger proportion of quick-shedding catchment. This, however, would have given a worse reservoir-site and would have entailed extra expense, both capital and annual, on account of the greater pumping-lift: the site higher up-stream was therefore adhered to. The startling results of 1902, however, could not be foreseen; and as, in the Author's opinion, the available records of rainfall render it more than doubtful whether, when the full estimated daily consumption is reached, even the 2 years' storage capacity will be sufficient to tide over bad seasons, the responsibility was incurred by him of recommending any necessary additions to the works. It was not considered advisable to raise the reservoir wall - although it is strong enough to bear some additional static pressure - since the limit of economy of the site has already been reached; and it has therefore been recommended that so

soon as the demand warrants that course, catch-water drains should be extended into the well-watered and quick-shedding country draining into the Helena below the present weir.

By this means, for an expenditure of about £45,000 (only 1 1/2 per cent of the total cost of the scheme), enough extra catchment area could be included to ensure a yield from the present reservoir of 6 1/2 million gallons daily - say 50 per cent more than what is now a certainty.

Evaporation and Loss from Reservoir - As will be explained later, the site of the weir was so badly fissured, and the basin of the reservoir so extensively crossed by basaltic dykes, that competent geological authorities believed that extensive stopping with concrete might be necessary. It was a matter of great interest, therefore, to ascertain what loss, if any, from the reservoir might result from this fractured condition; for it was decided that, except as regards the fissure across the site of the dam, no precautionary measures should be taken in the first instance. Between the 1st November, 1901, and the 28th February, 1902, no water at all was drawn, and a favourable opportunity for testing the probable annual loss was thus afforded. The total loss is at the rate of only 4 1/2 feet of depth per annum - which is not much more than the evaporation alone should amount to - the danger of building where similar basalt dykes occur can be seen to be not excessive. The point is one of the greatest interest in Western Australia, not only because the location generally of the streams in the ranges seems to have been determined by the greater ease with which these basaltic dykes have been disintegrated and eroded, but also because practically the only site available for the reservoir of the ultimate gravitation scheme for the West Australian metropolitan area, lately reported on by the Author, is even more fissured than that at Mundaring.

Quality of the Water - Except in a few tracts where salts have been leached out of the soil by heavy rainfall, even the surface waters of Western Australia generally, although soft, contain a comparatively large amount of dissolved mineral matter, chiefly common salt. High chlorine results have therefore to be expected on analysis, and this test of possible contamination of the sources of supply, whatever its value elsewhere, is inapplicable; but as the catchment is so large, and as much of the area was alienated before the scheme was inaugurated, and would cost an excessive sum to buy back, a small amount of habitation on the catchment is inevitable. Moreover, except in these small patches, the land is covered with forest and scrub; and, with a small ratio of off flow, the decaying vegetable matter would be expected to result in high ammonia figures on analysis of the water. Although this would in itself be harmless, it was recognized that the presence of the dissolved organic matter might be accompanied, on occasion, by dangerous bacteria of decomposition; and, as filtering

before delivery is not included in the scheme, it was determined to institute periodical analyses in the first instance, and, later on to make also regular bacterial examinations.

Disposal of Surplus Flood Waters - Although when the scheme was inaugurated there were no gaugings by which the probable total inflow into the reservoir from year to year could be arrived at with certainty, there was ample evidence to show that the Helena and other streams similarly situated were liable to heavy floods; and as at the site chosen for the weir the valley through which the Helena runs converges abruptly, being in fact a deep gorge flanked on both sides by high hills, the width at the bed of the river being only 15 feet, and at 100 feet above the bed 750 feet only from solid rock to solid rock, the usual method of disposing of flood-waters, namely, by means of a by-wash, was precluded by its cost. It was therefore decided to pass all floods over the weir crest, notwithstanding that calculation showed that for safety as much as 5 feet in depth over the whole length of the weir would have to be allowed for. Although, so far as the Author is aware, the weir is the highest overflow-weir in existence, this depth was not considered excessive, because no debris whatever is brought down in floods, which, even when of the heaviest, could not be of very long duration. Indeed, the whole flow of the river lasts less than half the year at most, so that sufficient time is afforded for repairing any damage done to the weir-face and footings. In order to facilitate the descent of the water, the profile of the weir-crest was approximated to a parabola, and the form of the curve follows very closely that of the Holyoke Dam, in the United States, which was determined by experiment. The reservoir overflowed for the first time during the rainy season of 1903, and, for about 2 weeks, 6 inches of water flowed over the crest without doing any damage to the wall. The water clung perfectly to the whole wall-face while descending. The same result is not to be expected when the depth over the crest is much greater; but obviously some departure of the deeper flowing water from the wall would not matter much. The downstream face of the dam is broken by three guide-walls which prevent any scour at its foot by the spill water, which would otherwise have run along the toe; and where the wall is highest, a spill-water basin or water-cushion has been provided, from which a wide channel, excavated in the river-bed and lined with stone, carries all flood-water rapidly away clear of the dam and of the pumping station below it.

The loss by evaporation and percolation has proved to be very small, and the overflow and draw-off arrangements of the reservoir have worked most satisfactorily.

II - CONSTRUCTION OF THE WEIR

The governing factors of the design were that the maximum pressure on any portion of the wall should not exceed 8 tons per square foot, and that the centres of pressure should be well within the middle third, both with the reservoir empty and when 5 feet of water was flowing over the crest.

Preliminary Works - The reservoir and the first pumping station are situated at the bottom of a deep valley some miles from the nearest railway, and as all material, except stone for the concrete of which the Weir was built, had to be brought from a distance, the first work put in hand was the construction of a tram-line, to the standard railway-gauge of the State, starting from Mundaring station on the existing line of railway. The next question was the provision, at a comparatively waterless spot, of a permanent supply of water fit for the use of the many men to be employed, as well as for the works. The requirements were met by constructing, in the bed of the future reservoir and about 9 chains above the weir wall, a temporary concrete dam impounding about 20 million gallons, and by forming, from the by-wash with which this small reservoir was provided, a channel capable of carrying away 100 million gallons per diem. The channel was formed for the most part of open cut, but a timber flume carried the flood-waters across the weir site.

Foundations - Generally speaking, the country at the reservoir site is very rocky, consisting largely of undecomposed granite, traversed by intrusive basaltic dykes whose direction is mostly at right-angles to the course of the river. At the site of the weir, however, the granite showed out particularly clearly, and the few trial-shafts, put down where the rock was shattered, reached solid granite at no great depth, the deepest of the shafts being only 20 feet deep from the ground surface. On opening up the foundations, however, it was discovered that the rock was nothing like as solid as surface indications and trial-pits promised; for on the right bank a large portion of what at first appeared to be bed-rock was found to consist of an immense boulder with a large cavity below it; and under the bed of the river the granite was very badly fissured over the full width of the foundations. It was not possible to vary the site, as the disruption was found to extend both up and down stream for a considerable distance; and there was no alternative but to follow the fissure down, which was done until a depth of 90 feet below river bed was reached. At this level the filling material in the fissure was found to be so compact that it was but slightly eroded by a jet of water discharged under a pressure of 250 lbs. per square inch. It having been seen that the fissure had a northern underlay, a vertical boring was now made on the north bank of the river, which cut the fissure at about 165 feet below river bed, and was continued for a further depth of 52 feet. The bore was

then filled with water, and the material in the fault was subjected to a hydrostatic pressure equivalent to a head of 690 feet, which was maintained for 4 hours, during which time the foot and hanging walls of the fissure, and the line of fissure at the bottom of the excavations, were all carefully examined; but no signs of moisture could be detected. It was concluded that the material in the fissure, at the depth which the excavations had then attained, was impervious to water, and that it would therefore be safe to erect the weir thereon.

Where the wall would be highest, that is, where the fissure occurred in the foundations, the excavations were carried down about 15 feet from the building-line in a vertical direction on the up-stream face; but as one of the basaltic dykes crosses the valley a short distance away on the down-stream side, it was considered necessary to remove the whole of the material between the hanging wall of the dyke and what would otherwise have been the toe of the weir. The concrete filling of foundations was carried up to bed level on the up-stream face, but on the lower side the mass filling was stopped 18 feet below bed-level and the wall proper was begun to the designed section. The granite beds, or floors, were deeply chased in longitudinal rows about 6 feet wide and 3 feet deep, and the toe of the wall-batter, where it met the granite floor, was channelled the whole length to key the concrete in.

The great inequality in the depth of the foundations, and their apparent doubtfulness for a work of this magnitude, have not appreciably affected the weir; for although very fine vertical lines, such as invariably occur in the concrete lining of service reservoirs in hot countries, have made their appearance here, they have not extended, and any slight sweats have taken up.

Drawing-off and Scouring Arrangements - The reservoir is provided with two valve-towers constructed of concrete. The inner tower, situated on the reservoir side of the weir, was built into, and concurrently with, the main wall, being approximately semi-circular in section. The outer valve-tower is rectangular in section, and is situated 175 feet down stream from the centre of the weir-wall, being connected therewith by a viaduct, which carries the outlet and scour-pipes, all solidly bedded in concrete, as far out as the outer valve-house. Ingress to the inner valve-tower is obtained by means of a steel gangway running over the crest of the weir, and supported thereon by granite cut-water piers 52 feet apart between centres.

Provision is made for drawing water from the reservoir at three different levels, namely, at 25 1/2 feet, 53 feet and 80 feet below full supply level, by means of 24-inch cast-iron bell-mouthed pipes, passing through the valve-tower wall into a cast-iron stand-post. Each draw-off inlet is provided with a stop-valve placed in the valve-chamber, from which valve-rods

are carried up to bevel-geared headstocks, all placed on the upper valve-tower floor, which is 1 foot 9 inches above maximum flood-water level of the reservoir.

Over each inlet are placed screens which can be removed for cleaning by means of chains worked by winches carried on an outer platform running round the valve-tower, and supported therefrom by brackets. Two 24-inch cast-iron spigot-and-faucet outlet-pipes pass from the stand-post, at 80 feet below full-supply level, through the weir-wall to the outer valve-tower. Each outlet is provided with a stop-valve in the inner valve-tower, and these are regulated similarly to the valves on the reservoir-inlets.

A 30-inch scour-pipe, leading from a fore-bay 90 feet below full supply level, runs through the inner valve-tower, and through the weir-wall into the outer valve-tower. It is provided with a stop-valve in the inner tower, which is worked by a worm-geared head-stock placed on the upper floor. From the outer valve-tower the scour passes into the river, where it has its discharge. Both the outlet-pipes and the scour-pipe are provided with valves in the outer valve-tower, which will be brought into use only in the event of accidents to the regulating-valves in the inner valve-tower. Any water soaking through the wall of the inner valve-tower is led into a sump, whence it can be lifted into the scour-pipe by means of a water-ejector, supplied with pressure-water from the lowest inlet. At the outer valve-tower, the two 24-inch outlet-pipes junction into a 30-inch pipe, which runs to the stand-pipe in front of the engines at No. 1 station.

The details of all the ironwork used in the construction of the weir were drawn out in the State, and all ironwork was obtained from Great Britain. It speaks well both for the accuracy displayed in the preparation of the drawings, and for the care exercised in the manufacture of the various appliances, that when being grouped together as the work progressed, all parts fitted correctly into their respective places, without any alteration whatever.

The site of the reservoir, about 800 acres in extent, was grubbed and cleared, and all fallen timber and decaying vegetable matter was taken out of the river-bed and burned; later on the suckers and scrub were again cut down and burned. About 20,000 acres of the lower catchment-area was ring-barked with the object of increasing the inflow.

A concrete-lined spill-water basin, about 150 feet long by 100 feet wide, is constructed in the bed of the river, at the toe of the wall, with a depth of water of about 10 feet. The water is confined by a mound across the river-bed constructed of rubble faced with concrete.

The excavations for the foundations were begun in May, 1898, and on their completion in January, 1900, the building of the wall was started, and was carried on both day and night until completion in June, 1902, an electric-lighting plant and eight arc-lamps placed at points of vantage affording ample light for operations by night.

Cement and Concrete - In the construction of the weir-wall 76,418 casks of cement were used, and a further 1,090 in the spill-water basin and other subsidiary works, or a total of 77,508 casks, of which 19,767 casks were of German manufacture and the balance British. The German cement was chiefly used in filling the deep excavations made in sinking on the fault in the bed of the river.

The length of the average passage by steamer from London to Fremantle was more than 6 weeks, and by sailing vessel 90 to 100 days; and as on arrival in the State the cement was received into storage-sheds where it lay at least 1 month, but generally for a longer period, during which time tests were made preliminary to its despatch for use, the cement had some chance of losing any "freshness" which it might have had when first placed in casks, and needed comparatively little slaking. A cement which did not demand much slaking before use was especially necessary in connection with the smaller scattered works of the scheme, distributed as they were over 350 miles, and mostly in country whose dry atmosphere would not tend to satisfactory, or, at any rate, speedy, slaking. In these smaller works, the cement, having passed the necessary tests, was used direct from the casks, because to slake and then repack it would have entailed incommensurate expenditure; but at the weir provision was made for slaking fully all cement requiring it.

The tests, which were of an exhaustive character, were directed not only towards determining the qualities of each batch of cement, but also to so ascertaining those qualities that after slight treatment in the State parcels which seemed at first to be doubtful might be used without hesitation. Situated, as the works were, at such a distance from the source of supply, this was essential. Taken altogether, the cements received were very satisfactory, and as the long-date tests become due, and the samples are examined and the briquettes broken, the results confirm the good qualities adjudged after the shorter tests.

One feature in the relative rise in temperature on hydration of slaked and unslaked cement is worthy of notice. On several occasions samples taken straight from the casks showed a comparatively small rise in temperature, yet the same cement, after exposure to the air, registered a considerable rise. For the purposes of closer examination a long series of experiments was made with the same shipment of cement air-slaked under three different conditions, namely:-

(1) Under the corrugated-iron roof of a shed.
(2) Under the wooden floor of the same building, spread in thin layers on a large tarpaulin and turned over daily; and
(3) Under the same floor, but placed in a box covered with wet bags, passages for currents of air being left between the cement and the bags, which were wetted and turned daily. It is difficult to assign reasons for the maximum rise in temperature shown in the results. However, the results obtained from long-date tests of this same consignment, show satisfactory increase of strength.

The effect of slaking on subsequent expansion was also the subject of a long series of tests. Ordinary glass test-tubes, 6 inches by 1 inch, were filled with stiff grout, and placed in cold-water baths after the cement had set. The tubes usually cracked after 3 days or more when filled with fresh cement, showing a high rise of temperature on hydration; but as slaking proceeded, so did the energy of the cement decrease. Further, there was apparently renewed activity after months of quiescence, tubes being cracked although the cement core itself remained hard and sound and, so far as the eye could detect, absolutely unharmed.

Except about 1,000 cubic yards of sharp, coarse-grained sand obtained from the river about 1 mile below the weir-site, the whole of the sand was brought from either Lion Mill or Bayswater, distant 8 miles and 22 miles respectively, by railway. That from the former was of quartz, and very fine-grained, yielding even and good results in the testing-room. The quarry, however, required heavy stripping of mould, and the sand itself required screening and thorough washing, to cleanse it from vegetable and earthy matters. This entailed the erection of a sand-washing plant. The sand from Bayswater was of a much better class, and required but light washing to free it from all earthy material.

About 30,000 cubic yards of spalls, for crushing to concrete size, were selected from the material obtained in the excavation of the foundations. For the plums and the balance of the spalls required, a quarry was opened on the north bank of the stream, below the weir, and about 70 feet above river-bed.

The weir and all accessories were built of concrete, but in the former, large rough granite blocks, just as quarried, were introduced into the concrete. It was originally intended to build the wall with 50 per cent of these large blocks; but without proper plant, which was not available, handling would have been very expensive. The concrete consisted of 5 parts by measurement of granite crushed to 2 1/2 inch gauge, 2 parts of cleaned sand and 1 part of Portland cement. So long as the wall remained below the level of the mixing-house, the mixture was conveyed to the work on an endless conveyor working in a trough, with travelling boards secured by ropes and spaced

2 feet apart, thus ensuring that the heavier aggregate was not separated from the matrix on the way. Later, the concrete was conveyed on a trolley-line in skips, to a large derrick-crane, which lifted the skips on to temporary tram-lines on the growing wall: they were then pushed by hand to a travelling steam-crane which lifted each skip in a bridle, overturned, emptied, and returned it to its carriage. The concrete was spread and rammed by hand, the various layers being broken up so far as the width of wall would allow, in order to break bond in both beds and joints; and in addition, the large rough blocks, up to 2 cubic yards in volume, were deposited and thoroughly bedded and grouted, in order to key the bedding-planes together.

For the first 10 feet the batter was lined and the concrete retained by rubble masonry, but above this level wooden framing was substituted.

Rendering of the face was not desired or found necessary, as great care was taken, when depositing the wet concrete in contact with the moulding-boards, to keep all stone well back with straight spades, and a good finished face resulted on stripping. The valve-tower and viaduct, which were carried up with the main wall, were similarly built between moulding-boards, the frames inside and out being formed of upright studs, cross silled and lagged with 4-inch by 1 1/8-inch tongued and grooved Oregon boards fixed vertically.

III - THE PIPE-LINE

The points on which the Commission of English engineers were asked to advise were, as regards pipes and main generally -

(a) *"Whether the pipes should be laid in a trench and covered in, or left exposed to view."*

(b) *"Whether it would be safe to rivet up the whole line of pipes, or whether joints, to allow for contraction and expansion, are necessary; the kind of joint most suitable, should they be necessary."*

(c) *"Material and method of manufacture of pipes, whether welded or riveted, and whether welding and riveting shall be square or spiral." The use of cast iron being prohibited by the cost and the difficulty of freight both by sea and by land, the Commissioners were not to take it into account.*

(d) *"The diameter and thickness of pipes, and method of protecting."*

As regards (a), the Commissioners were informed that there were possibly deleterious salts in the soil of a large part of the district through which the aqueduct would pass; and, for this reason, and also in order to avoid pressure on the empty pipes, to save the expense of trenching, and especially to facilitate detection and suppression of leakage, they recommended that the pipes should be laid above ground, uncovered, with expansion-joints.

The Commission recommended that the pipe should be of steel throughout, supported on bolsters, and riveted up in lengths of about 110 feet, with expansion-joints at these intervals, and anchor joints midway, fixed to masses of concrete or piles, in order to prevent the pipes from creeping. The minimum thickness was fixed at 13/16 inch; and the pipes were to be longitudinally riveted where the pressure was such that the thickness of shell for riveted pipe was not required to be greater than 1/4 inch, and welded for all higher pressures; with a minimum thickness of 1/4 inch.

Tenders for the pipes were accordingly invited from Australia, Europe and America. Tenderers were at the same time invited to submit alternative prices for any other kind of pipe which they desired to put forward. The lowest of the tenders received were as follows, the prices being for delivery in the Colony at a point 22 miles inland:-

Class of Pipe	Lowest Tenders received in	
	Europe	Australia
	£	£
Riveted pipes	782,708	682,827
Welded "	472,600	. .
Locking-bar pipes in lieu of welded pipes	. .	239,868
Total	1,255,308	922,695

The locking-bar pipe, for which alternative tenders were received, had been considered by the Commission and favourably commented on, but was not recommended for so large a scheme, because proof of its successful manufacture and use on any considerable scale was not then available. Subsequently, however, and before receipt of the tenders, 10 miles of main, 25 1/2 inches in diameter, had been laid in South Australia. It had been found that pipes made from 1/4 inch plate and fresh from the closing machine would withstand a pressure of 400 lbs. per square inch - or nearly twice what would be alloweed continuously in practice on pipes of this thickness of plate - without a weep; and, moreover, all pipes which did not stand the test could be passed back to the closing-machine to be reclosed, instead of being subjected to the usual caulking-processes so injurious generally to the plates and jointings. Practical use on a fair length of main also showed that the jointing could be successfullly accomplished, thus leaving only questions of comparative cost and comparative usefulness to be considered in deciding whether the new pipe should or should not be used in place of welded and riveted pipes.

Taking first the Australian prices for locking-bar pipes and contrasting them with those for welded pipes, the saving is seen to be very marked, being within a few pounds of 50 per cent. Moreover, the price of locking-bar pipes was but little more than that of riveted pipes. The lowest tenderers were therefore asked to consider the matter again, and they quoted prices for the locking-bar pipes which contrasted as follows with those received for the riveted pipes:-

Thickness of Metal in Pipe.	Riveted Pipe.			Locking-Bar Pipe.		
Inch.	£	s.	d.	£	s.	d.
3/16	12	12	9	13	10	0
1/4	16	5	0	16	15	0
5/16	20	3	6	21	0	0

Making a deduction of 1/16 inch from the thickness of the plate to allow for corrosion and contingencies, and assuming a safe working-pressure of 7 1/2 tons per square inch of net section of metal, the safe head of water on pipes of these thicknesses, and 30 inches in diameter, is shown by the following Table:-

Thickness of Metal Metal in Pipe.	Safe Working-Head	
	Riveted Pipe.	Welded Pipe.
Inch.	Feet.	Feet.
3/16	220	323
1/4	340	485
5/16	458	647

The locking-bar pipe being as strong as welded pipe, it would be possible to effect considerable economy by using 3/16-inch and 1/4 inch locking-bar pipes, in place, respectively, of the 1/4 inch and 5/16 inch riveted pipes which had been specified originally; but it was recognized in the State, when pipes of so small a thickness as 3/16 inch were included in those to be tendered for, that great care would be required in handling them, in order to prevent damage; and one result of the favourably low tenders was that a minimum thickness of 1/4 inch was provided throughout, thus greatly increasing the probable life of the main in the every portions where the soil is worst, and the variations in temperature greatest. Moreover, by having one thickness and one diameter throughout, the contractors were induced to make a further reduction of 5s. per pipe, so that the whole length of main was laid with pipes

30 inches in diameter, thus effecting some saving in the capital cost of the pumps, as well as in the cost of pumping.

As the adoption of locking-bar pipes obviated the serious and continuous loss of water which was to be anticipated from a pipe having multitudinous rivet-holes, the question was considered whether the soils in which the pipe would have to be laid would tend to shorten its life, and if so, to what extent. As already mentioned, the natural water obtainable on the goldfields is highly mineralized; moreover, it often contains free acids. Therefore thin unprotected pipes in contact with this water could not have any lengthy life - conclusion which experience has confirmed; but careful analysis of the soils along the pipe-track showed that, where mining operations did not entail distribution of such water on to the soil in which the pipes might be buried, this soil has been so much leached as to have lost many of its harmful properties, except, of course, in the salt-impregnated beds of the so-called "lakes". It was decided, therefore, that in the latter situation the pipes should be laid on trestles above ground, but covered with a low roof of galvanized iron; and that in the remainder of the section they should be buried, thus obviating any necessity for expansion-joints and permitting, in fact, the use of ordinary lead jointing.

The Coating - In determining the composition of the coating to be used, wide extremes of temperature had to be allowed for. The fierce and continuous heat of the goldfields summer, when the temperature in the sun attains 150° to 170°F., is sufficient to render even block asphalt plastic. On the other hand, the frosts of winter would injuriously affect too hard a coating; and, moreover, as experiments showed, the extreme dryness of the soil at certain seasons, together with the heat, would very likely cause some loss of essential oils. As the result of a large number of tests of mixtures, made both at the pipe-works and at the head office, the coating used consisted of one part of asphalt and one part of coal-tar applied as described later, and freely sprinkled with sand while still hot and soft, to reduce the risk of the coating running when exposed in hot weather. No doubt the latter object could have been brittle and more liable to flake off the pipes. Even the coating used ran to some extent when exposed for many days to the hot sun; but all exposure of metal, owing to this and other damage, was systematically made good just before the pipes were buried. The inside of the pipes was similarly coated - except, of course, that no sand was applied; but, as the water passing through is soft, although containing 20 grains of solids per gallon, and as vegetable acids are absent, much corrosion of the interior surface is not anticipated: and where the pipes have been emptied and opened 12 months after water started to pass continuously through them, the interior has appeared to be as clean and good as when they were first laid.

Joints - A simple sleeve joint was adopted, the ring being 8 inches wide, and 1/2 inch larger internally than the pipe externally, to allow for slight variations in the ring, and to permit of the use of lead filling throughout. For working-heads of 320 feet and less, the weight of ring used was 126 lbs; but for heads of more than 320 feet a stronger form was used, the weight per ring being 160 lbs. The finished jointing has proved very effective, the loss through leakage being small. From the pipes alone, on Sections 1-5, it was found to be 343 gallons per mile per diem. From the whole length of 295 miles between the storage-reservoir at Mundaring and the last pumping station it was found to be 480 gallons per mile per diem, over 10 months' working. This figure includes losses due to evaporation and percolation from nine pumping and break-pressure reservoirs of contents aggregating 16 1/2 million gallons. As a direct line from the Helena reservoir to Coolgardie does not deviate far from the railway already built to the goldfields, it was resolved that from Northam eastward the pipes should be laid parallel with the railway and at a distance of 45 feet therefrom; thus gaining the great advantages of easy carriage and, subsequently, of easy supply of water to the railway; but between the weir and Northam the railway was deviated from, in order to shorten the distance, and also for the purpose of traversing higher country and thus reducing the pressure on the pipe.

Where salt lakes or their beds occur, the main is carried on timber trestles, the pipes being surrounded by an insulation of saw-dust, which is kept in place by galvanized corrugated iron. This arrangement has been quite successful, no movements at the joints having taken place. Across the Avon River the pipe is duplicated, sunk beneath the bed of the river, and embedded in concrete. At railway and road-crossings, the pipe is also protected by a shield of concrete.

At intervals of about 5 miles, stop-valves are inserted, the diameter of the main being reduced by cast-steel reducing pieces to 21 inches. Where long rising gradients occur, reflux-valves are placed, the pipe being similarly reduced. Scour-valves are provided where required at both stop-valves and reflux-valves. The stop-valves are actuated by slow motion gearing, and, on sections where the water hammer was likely to be considerable, small by-passes were introduced, and so controlled that the water was brought to rest very slowly. Air-valves of the Glenfield pattern were placed at all summits, a nest of three being placed at the highest points, a nest of two at intermediate points, and a single valve at the lowest points. These valves are of the double type, provision being made for a large escape of air when charging the main, while air accumulating in the pipe is automatically discharged. This automatic discharge, instead of being obtained by varying the diameter of the ball, is effected by variation in the diameter of the orifice in the nipple. By this arrangement the nipple-orifices for the high points, where the pressure is

light but where larger volumes of air accumulate, are the largest diameter, and consequently afford the maximum provision for the discharge of air.

Manufacture of the Pipes - A pipe consists of two plates, each of the full length of the pipe and each bent to a semicircle. The edges are burred or beaded to the shape of a dove-tail, and are inserted in the open jaws of heavy longitudinal bars which are subsequently closed cold on to the edges of the plate thus forming longitudinal dovetail joints. The steel used in both plates and bars was open-hearth basic steel with a specified tensile strength at first of not less than 25 tons, or more than 29 tons, per square inch. Experience gained in the manufacture of the pipes, however, showed that steel of this quality was somewhat too hard for the bars, which, owing to the cold working, failed under test by the bursting of the jaws before the plates were ruptured. It was also found that when bars weighing 6 1/2 lbs. and 7 3/4lbs. per lineal foot were used, respectively, with 1/4 inch and 5/16 inch plates, the bars failed before developing the full strength of the plate: consequently, the respective weights of the bars were increased to 7 lbs. and 8 1/4 lbs. per lineal foot, the steel in the bars being of a tensile strength of between 22 tons and 26 tons per square inch. From each week's output of pipes at the works pieces were cut and tested to destruction.

The pipes were made in Western Australia from imported plates and bars. Of the former, one-half were brought from Germany, and the balance from America; but all the bars and the joint rings were obtained from England. The plates, which were a trifle over 28 feet long by 4 feet wide, were first passed through horizontal rollers, three above and three below, for the purpose of taking out all kinks and rendering the plates perfectly straight. They were then cut square and to the exact length of 28 feet. The planning and dovetailing machine next cut them to the exact width, and then burred the edges by means of rollers to form the beading for the dovetail joint.

The plates next passed through a longitudinal press wherein both edges were given the required curvature, thus avoiding any necessity for the beading or dovetail being passed between and damaged in the curving-rollers to which the plates were now brought, to be bent into semicircles in the usual way. On completion of this process most of the scale had been loosened and detached, and the plates, having been thoroughly cleansed of all remaining scale and rust, were ready to be formed into pipes. One semi-circular plate was now placed in a row of half circular cramps, resting on seats, and a locking-bar was fitted over each edge. Another semi-circular plate was then inverted and lowered until its edges rested in the upper grooves of the locking-bars. The upper halves of the cramps were then placed over the top of the pipe and connected to the bottom halves, and the plates were brought firmly home into the grooves of the

locking-bars by tightening the cramps with cotter-pins. The pipe in its encircling cramps was then conveyed to a hydraulic closing-machine capable of developing a pressure of about 1,200 tons, wherein the locking-bars were pressed on to the plates, completing the manufacture of the pipe. The whole of the operations were performed without heating plates or bars.

Each pipe, before being passed, was subjected to a hydraulic pressure of 400 lbs. per square inch. The closing of the locking-bars was so effectual that only a small percentage of the pipes were found to sweat at the bars. These were returned to the closing-machine and re-pressed, and this was found to stop the sweating effectually. About fifty pipes failed altogether in the joint under this test.

After being tested and passed, the pipes were coated. They were first heated to a temperature of 300^{o}F. and then placed in a bath consisting of a solution of ordinary gas-tar and Trinidad asphalt, in the proportions already stated, and kept at the boiling-point. On being lifted from the bath the pipes were allowed to drain for about a minute, and were then revolved in a machine while a jet of cold air was forced through them, for the purpose of ensuring that the coating should set in a uniform thickness. When it had cooled considerably, and just before setting, a sprinkling of sand was thrown over the outside of the pipe and gently pressed into the coating by means of rollers.

After all initial difficulties common to new methods of manufacture had been overcome, the pipes were turned out finished at the rate of 150 to 160 per diem from two factories, each of which worked two shifts of 8 hours each.

Conveying, Distributing and Unloading Pipes - The whole of the pipes had to be conveyed on the trucks of a single-line railway of 3 foot 6 inch gauge. Most of them were laid alongside this line, but those which had to be taken across country when the pipe-line deviated from the railway were conveyed from stations or sidings on specially constructed carriages. The pipes had to be distributed from the trains very quickly, so that the ordinary traffic on a fairly hard-worked railway would not be interfered with.

The unloading contingent of men, consisting of four gangs who, up to the arrival of the train, had been engaged on the excavation of the pipe-trench, then took charge. Each of these gangs consisted of six men, including a leading hand who controlled the gang's operations. Each gang had generally three trucks to unload, and when the train consisted of an odd number of trucks, the extra truck was allotted to the gang first getting to work. The average time occupied in unloading, from the time the loaded train left the siding until it returned thereto with the empties, was about 1 hour and 20 minutes, but the unloading was frequently done in less that

1 hour. During the remainder of the day the unloading gangs were kept at work on the excavation of the pipe-trench, sections of which had been left for this purpose. This system worked admirably, there being considerable rivalry between the various unloading gangs, and the general railway traffic was not interrupted.

Joints - As the whole length of main is of uniform diameter, the possibility of using machinery in place of hand-caulking of the lead joint was considered at an early stage. Careful trial at headquarters of joints caulked by hand and by a machine devised by a local firm, demonstrated that, whereas the machine made joints when subjected to hydraulic pressure attaining 400 lbs. per square inch remained quite water tight, on the other hand, slight sweats and pin-squirts manifested themselves in the hand made trial joints submitted to the same test. As a 30 inch pipe of 1/4 inch plate springs somewhat, even under the impact of a very light blow from the caulking hammer, it is somewhat difficult to get hand-caulkers to finish a joint water-tight; moreover, in practice, men working in constrained positions for long hours, in manholes under the pipe joints, cannot be expected to do uniformly good work. On the other hand, the machine caulking can be done by pressure applied uniformly on both sides of the joint ring, and quite as uniformly on the lower as on the upper side of the pipe. Machine caulking was therefore decided on, with the good results in freedom from leakage already stated.

The caulking machinery consisted of a portable oil-engine of the spontaneous-ignition type, built in Australia, and of about 5 1/2 BHP. The underframe of the engine also carried a dynamo which was belt-driven off the engine fly-wheel. The current was transmitted through a cable 1/4 mile in length, so that about 1/2 mile of pipe could be caulked before moving the generating-plant to a fresh position. The cable was coiled on a drum carried on the after part of the transport also carrying the caulking-machine, and a plug contact was used for connecting cable and motor, so as to permit of unhampered coiling and uncoiling of the cable on the drum. The caulking-machine was in two halves, one fitting over and the other under the joints of the main, and on the top half of the outer frame was carried the electric motor which was belt-connected to a shaft, and by means of intermediate gearing worked the rims holding the caulking-tools. These rims or racks were guided by small, hardened steel rollers, grooved on the outer circumferences of the racks, but plain on the inner circumference.

Into jaws on the racks were slipped the caulking-tools, two in each rack, one operating on the upper half of the joint and the other on the lower half, i.e., on the underside of the pipe.

The caulking-machine was mounted on a transport on which it was carried along the top of the pipe, from joint to joint, the lower half of the machine being slung on the transport side by side with the upper half. On arrival at a fresh joint the lower half was lifted off, placed over the joint, and slid round it to the underside; the upper half was then lowered, and the two halves were fastened together, racks were clipped and the tools placed in position, the plug-connection between drum and motor was made, and the machine was started, the caulking-tools working round the pipe backwards and forwards until the lead was pressed home. The number of semi-revolutions found necessary ranged from five, where the caulking-rollers were 1/4 inch thick, to seven, where 5/16 inch or 3/8 inch rollers had to be used to meet the varying distance between the inner surface of the joint-ring and the outer surface of the pipe. On completion of the caulking these tools were replaced by knives, which cut off the fillet in the last semi-revolution, bringing the racks back to their original position, and thus permitting the machine to be dismantled and moved to the next joint. When once fairly started, the operations were carried on without hitches, and the machinery of all descriptions, including motors and dynamos, worked well, notwithstanding that it was usually working in a cloud of dust due to the proximity of the trench-filling operations.

Each installation required three men (one a mechanic) for the working and transport of the caulking-machine, one man for the engine and dynamo, and two hand-caulkers, whose special function was to caulk at the locking-bars, whose projections prevented the rollers from working right round the pipe. In addition there were rollers from working right round the pipe. In addition there were charges for parts of the time of mechanics and others whose duty it was to keep the electrical and other machinery in repair. The whole immediate cost of an installation per diem amounted to £5. 1s. 4d.; and as the average day's work when the initial difficulties had been overcome was thirty-one joints, the cost per joint was 3s. 3d., or 1s. less than hand-caulked joints were actually costing. In addition, the saving in the average size of manhole necessary was 1 3/4 cubic yards; and these two savings counterbalanced the whole cost, including the patent-rights of the machinery. There is no doubt that, with the experience gained, machine-caulking could be rendered cheaper than hand-caulking, especially for a circular pipe without projections; but the object in this case was to obtain uniform and certain work, and this was attained without extra cost.

Excavation of the Trench - The surface formation of the country traversed is very irregular. On the plains, ironstone conglomerate predominates, but never extends continuously for more than a few chains at a stretch, being broken by bands of sand, diorite, and granite. In the timbered belts, sandy clay is the usual surface soil, but with outcrops of granite, diorite, and schist interspersed. Where at all possible, the

material to be taken out was loosened by means of ploughs, each drawn by four horses harnessed in single file in the line of trench, and working to any depth required; but the bulk of the trench was taken out by manual labour, and it was necessary to use explosives on more than one-fourth of the total material removed. Where the material could be moved without the use of explosives, it was found that the most economical depth of trench, with due regard to cost of obtaining cover-material, was about 3 feet 3 inches. Where the country was harder, the trench was taken out to a less depth, the principle kept in view being that the cost of the trench, added to the cost of cover, should be a minimum. Occasionally, the contour of the ground would not admit of economical grading in combination with proper alignment for the pipes, and, in such cases, cost was subordinated to the more important consideration of easy alignment of the main. The excavation of the trench was kept well ahead of pipe-distribution, laying and jointing, but in order to provide continuous work for the gangs on these latter operations, should any hitches occur in the arrival of materials, sections of trench were left unexcavated at intervals.

Laying and Jointing Pipes and Filling in Trenches - The work was divided into sections of about 14 miles each, to be dealt with by one caulking-installation, and when the work was completed the whole gang went forward to the next available section. When the works were brought into full swing, seven such gangs were at work on several sections; and, the class of work performed by each being identical, there was considerable rivalry between the parties. Bad work, due to haste, was prevented, however, by the appointment of an inspector on each section, who reported directly to the head office and was responsible only for the quality and not for the cost of the work, thus placing these departmental operations on the same footing as those of a contractor. The rate of progress during the last 3 months before approaching completion caused disbanding, was, per day of 8 working-hours of seven gangs, 1 2/5 mile of laying, jointing, and complete filling-in of trenches. The appliances in use by each gang consisted of two pipe-lowering trestles, four skids, one pipe-expander, one lead-melter and retainer, and the engine and caulking-plant. The lead-running gave great trouble until the lead-melter was devised, after which honeycombing and other faults were prevented.

The sequence of the various operations was carefully regulated. Foremost were the men repairing the coating in the parts damaged during unloading or transportation, or where it had become defective owing to exposure for a considerable time to the intense summer heat; and in the same set were the pipe-scrapers and locking-bar chippers, who chipped or scraped off the coating at each end of a pipe for a distance of about 6 inches, to ensure good lead-running. Next came men cutting manholes, a little ahead of those laying the pipes in the

trench, and following these came the ring-setters, who wedged up the joint-ring to such gauge as would give a lead joint of uniform thickness. In succession were the lead-runners, whose work was, when possible, kept at least forty or fifty joints ahead of the caulking-machine, especially in winter, as showery and cold weather affected the quality of the lead-running: thus stoppage in such weather, or defective work which had to be remedied, did not delay the caulking-operations. Following on were the hand-caulkers, who caulked the joint at the locking-bar and for a distance of about 4 inches on each side of it. The best results were obtained not by allowing the hand-caulking to finish abruptly, but by tapering up the the uncaulked portion; by this means the machine rollers were able to work by degrees well back on to the hand-caulked portion; with an abrupt finish of the hand-caulked portion, the machine rollers were liable to race and cause breakages. This racing could of course have been avoided by extra care on the men's part, but at expenditure of unnecessary time, to save which would have entailed the danger of the rollers not being brought far enough along, thus leaving the joint imperfectly caulked at the junction of hand and machine work. After the hand-caulkers came the machine, and as each joint was finished the joint-inspector examined it; pipes were covered to a depth of at least 12 inches as soon as the inspector had passed a joint and it had been tarred, so that the partial filling in was only two or three joints at most behind the machine. The completion of the filling-in and the formation of the covering link was always 400 yards or more behind the machine.

Charging the Main - By the 13th April, 1902, the works were sufficiently far advanced to enable pumping to be commenced with one of the engines at No. 1 station. No trouble was experienced in getting the engines underway; in fact, practically no hitch whatever occurred at any of the eight pumping-stations, and after once starting at any station the machinery was in condition to be worked, and was worked, whenever desirable. By the 22nd April the water had reached the Cunderdin Reservoir, at mile 77. Four months now elapsed before the laying and jointing of the next section was completed, and it was not till the 22nd August, 1902, that the water reached the Merredin receiving-tank at mile 140. Some little trouble was experienced in charging this section, through the joints leaking, due mostly to the subsidence of the pipes laid across the bad ground in the bed of the Mortlock River and adjacent soft country. It was through leakage of some of the joints on this section that what may be described as "sand cuts" were first experienced. They were caused by the joint action of the escaping water and the falling sandy covering, playing together on a small portion of the outer surface of the pipe. This action is somewhat similar to that of the sand-blast, and, under favourable conditions, one of the thin pipes used could be cut through in 4 to 6 hours. Fortunately, only six cases of the kind have been experienced so far. If discovered early, the placing of an encircling band

on the pipe (such bands were kept in readiness) met the difficulty; but if the plate of which the pipe was made had a hole entirely or nearly cut through, a length of the main had to be emptied and the damaged pipe was replaced. To guard against occurrences of this nature, the upper halves of the lead joints were subsequently kept uncovered for some little time in country of a sandy nature, and where the main is under a head of 300 feet or more. The water reached the Coolgardie service-reservoir, at mile 328, on the 22nd December, 1902, and, finally, the Kalgoorlie service-reservoir, on the 16th January, 1903, about 8 months after the charging of the main was started. The pumping was restricted to an amount sufficient to fill about 12 to 15 miles of main per day, and, at this rate of charging, no trouble from air-pocketing was experienced, it being found that the air-valves had sufficient discharging capacity to pass the volume of displaced and escaping air. The whole or part of the main has now been conveying water for nearly 2 1/2 years without a burst having resulted either in the main or in the valves or other specials: the only occasions on which it has been necessary to empty any portion of the main have been when the "sand cuts" have occurred.

IV - THE PUMPING MACHINERY

Frictional Resistance of Pipes - It was originally calculated that for a discharge of 5 million gallons per diem through 30-inch riveted pipes the frictional resistance per mile would be equivalent to a head of 4 feet, which was obtained by applying Kutter's formula with a coefficient of roughness of 0.015, a figure deduced from the measured frictional resistance of the 48-inch riveted pipe of the East Jersey (U.S.) Water Company. But the change to a much smoother pipe allowed of a considerably reduced provision. The Commission of English engineers had proposed a frictional allowance of 2.5 feet per mile for welded pipe; but, in view of the class of water to be dealt with, this allowance was increased by 20 per cent; and as it was further determined to increase the daily quantity to 5,600,000 gallons, the ultimate allowance was raised to 3.76 feet per mile. On completion of the works, two tests, each of 12 hours' duration, were made, one over 22 miles and the other over 12 miles of pipe, the results on reduction showing an average resistance equal to 2.25 feet per mile for a discharge of 5,000,000 gallons per diem, or 2.8 feet for 5,600,000 gallons. These results, being for clean pipes, are considerably less than the ultimate estimates; and this was foreseen, the main was laid to an even less fall than 2 1/4 feet per mile, in order to save unnecessary present pumping.

The total ultimate friction-head for the whole distance from the weir to the main service-reservoir at mile 307 1/2 of the aqueduct, calculated at 3.76 feet per mile, amounts to 1,156 feet, and the natural lift to 1,290 feet; and the aggregate loss at seven pumping-stations for reservoir provision being 122 feet, the total head to be provided for is 2,568 feet: but elevated ground between pumping-stations Nos. 2 and 3 made it necessary to raise water 87 feet higher than if the slope had been gradual, thus making the total head to be pumped against 2,655 feet.

The great advisability of keeping the machinery to uniform size and pattern finally determined that the pumping-stations, eight in number, should provide for a total lift, including friction, of 2,700 feet or 45 feet more than was absolutely necessary - namely, 450 feet at the first four stations, and 225 feet at the last four. The waste head thus amounts to a trifle less than 1 3/4 per cent. Moreover, in regard to the advisability of uniformity, it was further decided that the first four stations should be fitted with three groups of machinery, any two of which should be capable of performing the required work; and that the last four stations should similarly be fitted with two groups, each capable of lifting the full quantity per diem. The power necessary had thus to be the same in every group, namely 265 effective HP., but to allow for deterioration and contingencies the pumping power contracted for was nearly 303 1/2 HP., or about 14 1/2 per cent extra.

The requirements and provisions may be summed up thus:-

		HP.
Effective horse-power necessary	. . . .	3,129
" " " provided for work	. . . .	3,642
" " " " as reserve	. . .	2,426

Tenders for the necessary pumping-machinery were invited in April, 1899, makers being permitted to submit alternatives as in the case of the pipes. In the result a contract was entered into with Messrs. James Simpson and Co., in March, 1900, for twenty groups of machinery at an aggregate cost of £242,750, excluding spares, but including erection. A detailed description of the machinery is outside the scope of this Paper, which, however, would be incomplete without the following brief account, and results of tests.

Description of Machinery - The pumping-plant consists throughout of almost identical sets, the only difference being that in the first four stations the pump-plungers are 15 inches in diameter, working against a specified head of 450 feet, while in the second four stations the diameter is 21 inches and the head 225 feet. The engines are horizontal, six-cylinder, high-duty, triple expansion, surface-condensing engines of the Worthington duplex, direct acting type, the diameters of the high, intermediate and low pressure cylinders being respectively 16 inches, 25 inches and 46 inches, the normal stroke of the pump-plungers 36 inches, and the piston-speed 150 feet per minute. The pump-plungers are externally and centrally packed, and directly connected with the steam pistons. The pump-valves are of stamped bronze. The steam-cylinders are jacketed throughout on heads and barrels with steam at boiler pressure, and the steam is re-heated on its passage both from the high-pressure to the intermediate-pressure, and from the intermediate-pressure to the low-pressure cylinders. The re-heater tubes which draw their steam from the cylinder-jackets are placed low, thus being the means of drainage for both cylinders and jackets. The steam-distribution is controlled by Corliss valves, placed in the cylinder-heads, and the cut-off in all cylinders is adjustable by hand while the engines are running. From the air-pump the condensed steam passes through an exhaust heater placed in the exhaust steam-main to the condenser, and is delivered into an elevated feed-tank in place of the ordinary hot well. From this tank the water gravitates to a Webster heater and oil-separator where it is further heated by admixture with the jacket-condensation and with the exhaust from the boiler feed pump. From the heater the feed-water is pumped by a Worthington feed-pump through the economizer back to the boilers. Steam is supplied by a nest of Babcock-Wilcox water-tube boilers, each designed to supply the necessary quantity for one engine, and having eighty-one tubes 18 feet long and 4 inches in diameter, a single drum 23 feet 7 inches long and 4 feet in diameter, with a superheater placed between

water-tubes and drum. A Green economizer is provided for each installation. The chimney-stacks are of steel, 5 feet in diameter; those at the first two stations are 130 feet high, at the third and fourth stations 100 feet, and at the last four stations 90 feet.

At six of the pumping-stations, reservoirs 15 to 20 feet deep have been provided adjacent to the machinery, to receive the discharge from the main and to furnish a store for the pumps to draw from; and in order to reduce suction lift and facilitate pumping, the centre line of the pump-plungers has been kept below the top of the reservoir by about 8 feet. At stations Nos. 1 and 3, however, special arrangements were necessary. At No. 1 the pumps, if connected directly with the main from the large storage-reservoir, would have been subjected to a head of about 100 feet when this reservoir was full; and at No. 3, where there is 3/4 mile of main between the large reserve reservoir and the pumps, the latter might have suffered from an undesirable hammer. The difficulty was overcome at each place by the provision of a stand-pipe open above, from which, as from a reservoir, the pumps draw.

The stations are brick buildings with corrugated iron roofs. The engines and pumps rest on granite bed-stones supported by brick piers resting in turn on a concrete floor. The pump-ends are bolted down to the bed-stones, but the cylinder-ends are allowed to move freely on expansion-rollers. The greatest care was taken in the laying of the foundations, only the best available material being used; and so far there has not been the slightest perceptible movement in the foundations of any of the twenty groups of machinery. The lower floors of the engine-rooms are of concrete rendered with cement mortar, and the upper or working floors are of jarrah timber resting on steel joints. The floors of the boiler-rooms are of concrete.

Efficiency of the Machinery - The tests provided for by the contract were three, namely, (a) for the duty of the whole machinery under present conditions, that is, head low owing to clean pipes and new boilers worked to full pressure; (b) for the duty of the engines and pumps with steam at full pressure but the pipes throttled to obtain ultimate estimated head; and (c) for the capacity of the pumps with the pipes throttled and the boilers worked at 25 lbs. per square inch below present full pressure.

V - THE PUMPING AND SERVICE RESERVOIRS, RETICULATION, ETC.

The reservoirs provided are intended for three different uses, namely, to act as receiving and suction tanks, to regulate flow in the main, and for service purposes. There are seven suction tanks, namely, one at each pumping-station except the first, the pumps of which draw from the storage-reservoir at Mundaring. Of the seven, all but one are concrete-lined tanks, the exception is the large 10-million gallon reservoir at mile 77, which was built some years previously for railway purposes and was taken over, as it is large enough to furnish a substantial reserve in case of accidents to the main or other works in the preceding portion of the scheme. The regulating tanks, two in number, are also concrete-lined and are much the same in design as, although smaller than, the receiving and suction tanks. That at Baker's Hill, regulates the flow at what is the highest point on the long and irregular section between pumping stations 2 and 3; and the tank at West Northam not only reduces the extreme possible pressure on the pipes in the Avon valley by 100 feet, but also permits of regulation of the flow in such manner as to keep the pressures at a minimum in regular working. The service-reservoirs are three in number, namely, one of 1 million gallons at Coolgardie, one of 2 million gallons at Kalgoorlie, and the large one at Bulla Bulling. The two smaller reservoirs are concrete-lined, and otherwise much the same as the receiving and suction tanks above mentioned, being also provided with by-passes so that in case of accident or necessary cleaning the working of the scheme need not be interrupted.

The main distributing-reservoir at Bulla Bulling which has a capacity of 12 million gallons, with an available depth of 20 feet, is rectangular in shape, two of the sides having slopes of 1 to 1 for the full depth of the reservoir, while the other two sides are vertical for a water depth of 8 feet from the top and then slope to the bottom of the reservoir. The vertical portion or wall rests on a bench 6 feet wide, from the inner edge of which the sloping lining is carried down to the bottom of the reservoir. The material of the reservoir-basin consists of indurated clay, ironstone conglomerate, and bands of limestone, the whole being badly fissured and pervious to water, and liable to disintegration and to slides due to greasy backs. The Author's experience of concrete-lined reservoirs on the West Australian goldfields had been such as to show conclusively that concrete lining, even 2 feet thick, would crack when exposed to the sun; and, moreover, the cost of thick lining in a reservoir of this size would have been excessive. It was therefore determined to limit the thickness of lining to 12 inches and to provide joints in the concrete to take the inevitable movements due to expansion and contraction.

The floor of the reservoir, 12 inches thick, was put down in two layers, the first or bottom layer being 8 inches, and the top layer 4 inches thick. In the centre of the bottom layer, a grillage of barbed wire, spaced 12 inches apart, was put in, for the purpose of adding tenacity to the concrete, and thus giving it greater power to resist cracking under contraction. The upper surface of the bottom portion of the floor was purposely left smooth, so as to allow the upper layer to slide thereon. By this arrangement, the top portion acts as a false floor, and any temperature cracks are not so liable to continue into and through the bottom portion as would be the case with the floor built in one layer. At the junction of floor and sides a bituminous joint, 6 inches deep by 1/2 inch wide, is provided. The sides and walls are also reinforced with barbed wires running horizontally and placed 9 inches apart. The sides and walls were built in sections with a bituminous joint between each pair. This arrangement effectually confined the results of contraction to the joints themselves, nearly every joint opening more or less at the faces, while the remainder of the lining remained intact. Soon after first filling, the reservoir, much of which was built in intense summer heat, was found to be leaking at the rate of 1 1/4 inch in vertical depth per diem; but instead of being spread in irregular cracks all over the reservoir, the leaks were confined to the lines on which the above-mentioned joints occurred: they were easily located, and were effectually stopped by cutting out portions of the joints to a depth of 2 or 3 inches, caulking with oakum, and facing with bitumen and tar.

Reticulation - The original scheme did not allow for any reticulation of townships for domestic purposes, or of mining centres, it being only intended to bring the water to some high hill - for instance, Mount Burgess a few miles north of Coolgardie - and to lay a subsidiary main thence to such situation in each township or mining centre as the local authority should choose for its service reservoir. Eventually, however, the complete reticulation of the townships of Kalgoorlie, Coolgardie, Boulder, and the Kalgoorlie Mining Belt, had to be undertaken as part of the main scheme, in addition to the laying of small pipes to mining centres near Coolgardie and Kalgoorlie; but one or two of the smaller townships, namely, Northam and Southern Cross, have installed their own reticulation, purchasing water in bulk from the main scheme, and retailing it to the ratepayers.

A separate telephone-line for the works was laid down between the head office at Perth and Kalgoorlie. It is of ordinary type, with one repeating station about half way, and was extremely useful during construction. Connection is thus secured between the head office and the pumping stations, and, by means of field telephones, with the maintenance gangers.

VI - COST OF THE WORKS

The actual cost, including all extras, contingencies, and establishment charges, was £2,660,000, an excess of £225,000, or 9 1/4 per cent., on the original estimate, after deducting from the latter £65,000 for works which were allowed for therein but were not carried out. This can hardly be considered a large excess when it is remembered that the original estimate was based on tentative data prior to survey; but as a matter of fact almost the whole of the excess is accounted for by one item alone, namely, pumping-plant, partly due to somewhat more water having to be pumped, partly to the provision of more reserve power for accidents, and largely to enhanced cost per horse-power. Low-duty engines were originally allowed for at an estimated cost of £22 per horse-power, while the actual cost of the plant installed was nearly £48 per horse-power, including Federal customs duty, spares, etc. So long as the consumption of water remains much below the ultimate amount allowed for, and so long as cheap local fuel remains available, the high-duty will not prove as economical as the low-duty and cheaper plant would have been; but the conditions will be different when the full consumption is reached, and utilization of the more costly fuel becomes necessary.

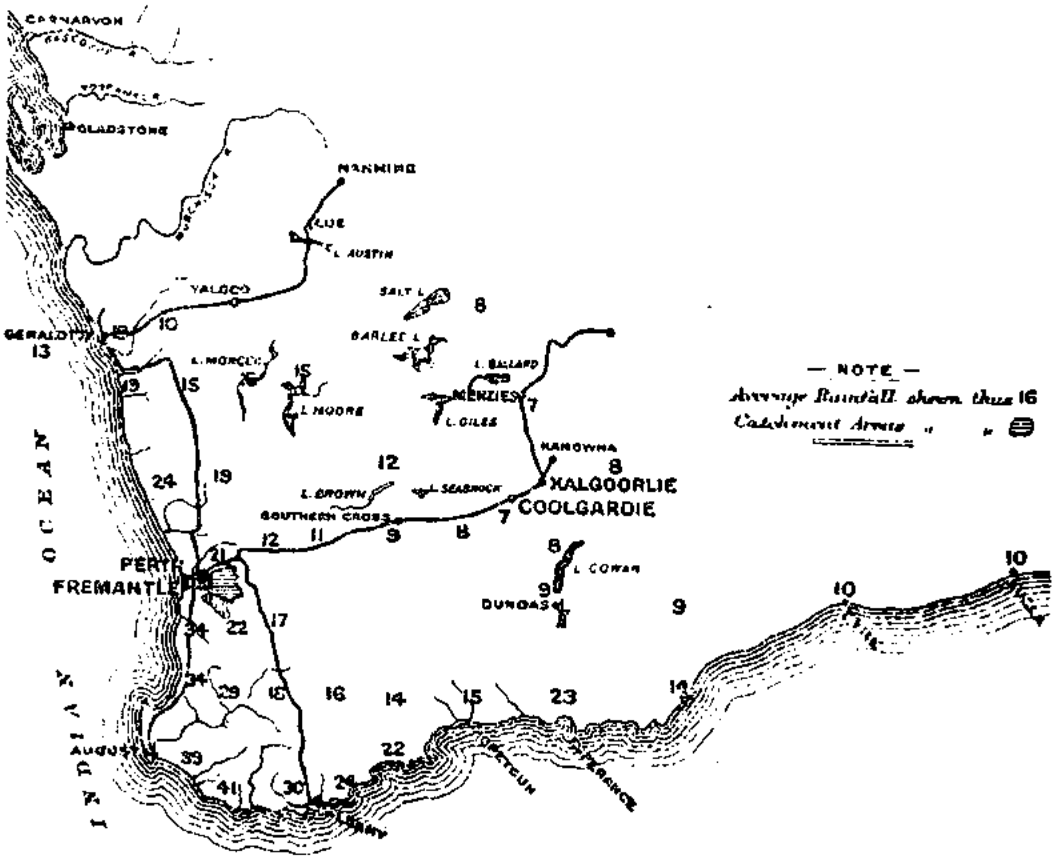
The total expenditure of £2,660,000 was sub-divided as follows:-

	£
Storage-reservoir, including 5 miles of railway-line, land-compensation and river-training works (capacity of reservoir being 4,600 million gallons, the cost is £61 per million gallons of storage).	280,000
Service and break pressure reservoirs of a total capacity of 16 million gallons (£3 3/4 per 1,000 gallons)	60,000
Conduit 352 miles long, including all valves and specials (£5,312 per mile)	1,870,000
Pumping machinery, including erection, freight, Federal customs duty and spares (nearly £48 per horse-power)	296,000
Pumping stations, exclusive of machinery but including the buildings, employees' quarters, suction-tanks, railway-sidings, coal-staithes and stores (£23 per horse-power)	140,000
Telephone-line and other contingencies	20,000
	£2,660,000

On the death of Mr. O'Connor, in March, 1902, the Author succeeded him as Chief Engineer, when about one-half of the works had been constructed. The progress was largely governed by the necessity for testing the long lengths of main between the various pumping-stations as soon as possible, and also by the rate at which the valves and specials could be obtained from England.

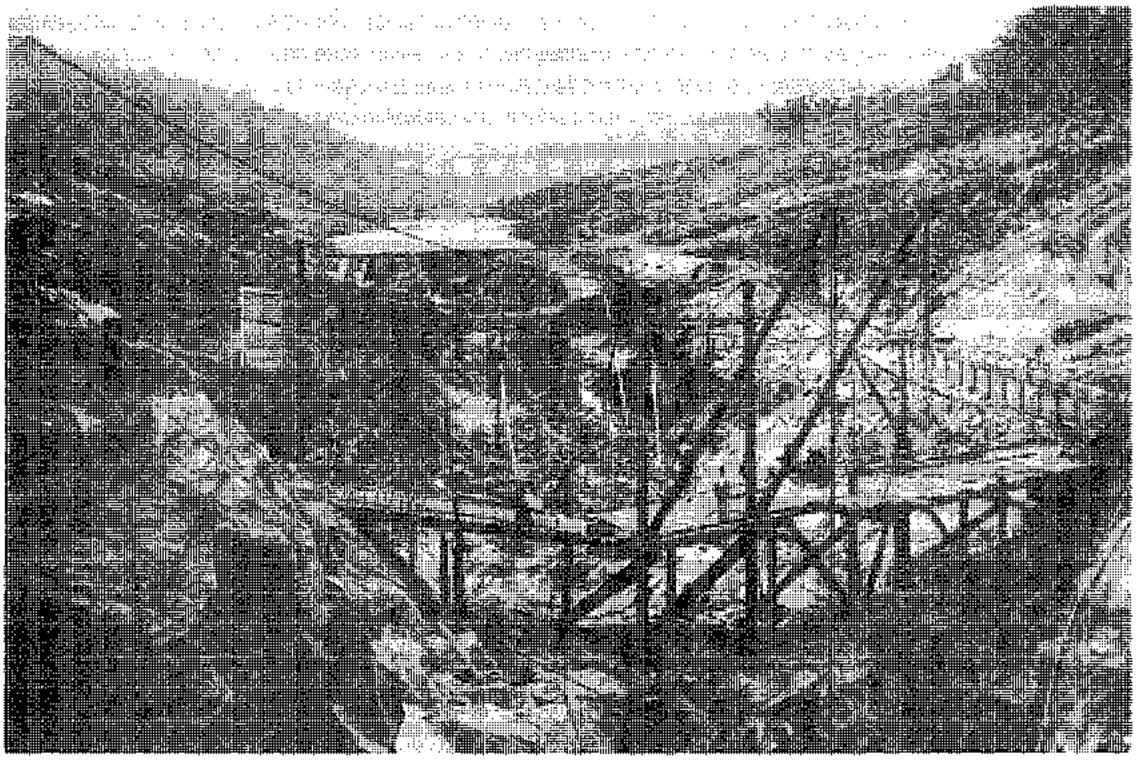
In conclusion the Author wishes to express his obligation to Mr. William Coates Reynoldson for much assistance rendered. Mr. Reynoldson was the Author's principal assistant on the scheme, and is now in charge of the works as Engineer to the Trust which was constituted by an Act of the West Australian Parliament for maintenance and management of the works.

PHOTOGRAPHS AND FIGURES

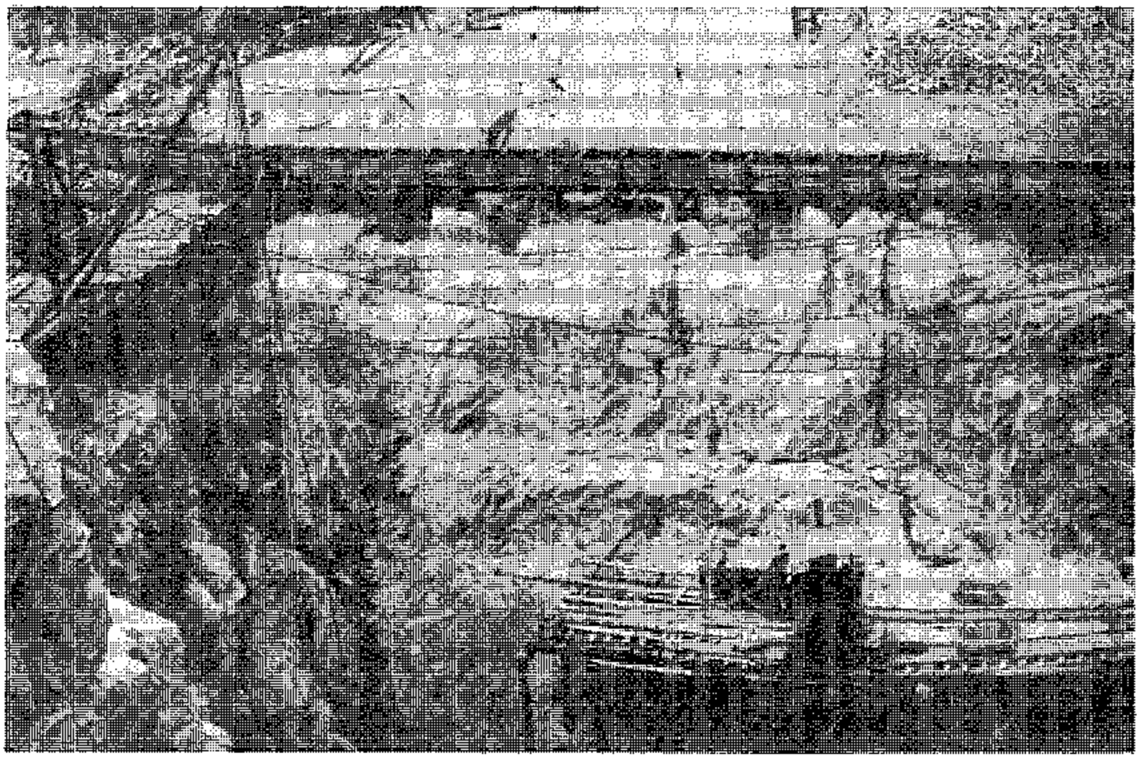


Scale 1 Inch = 250 Miles

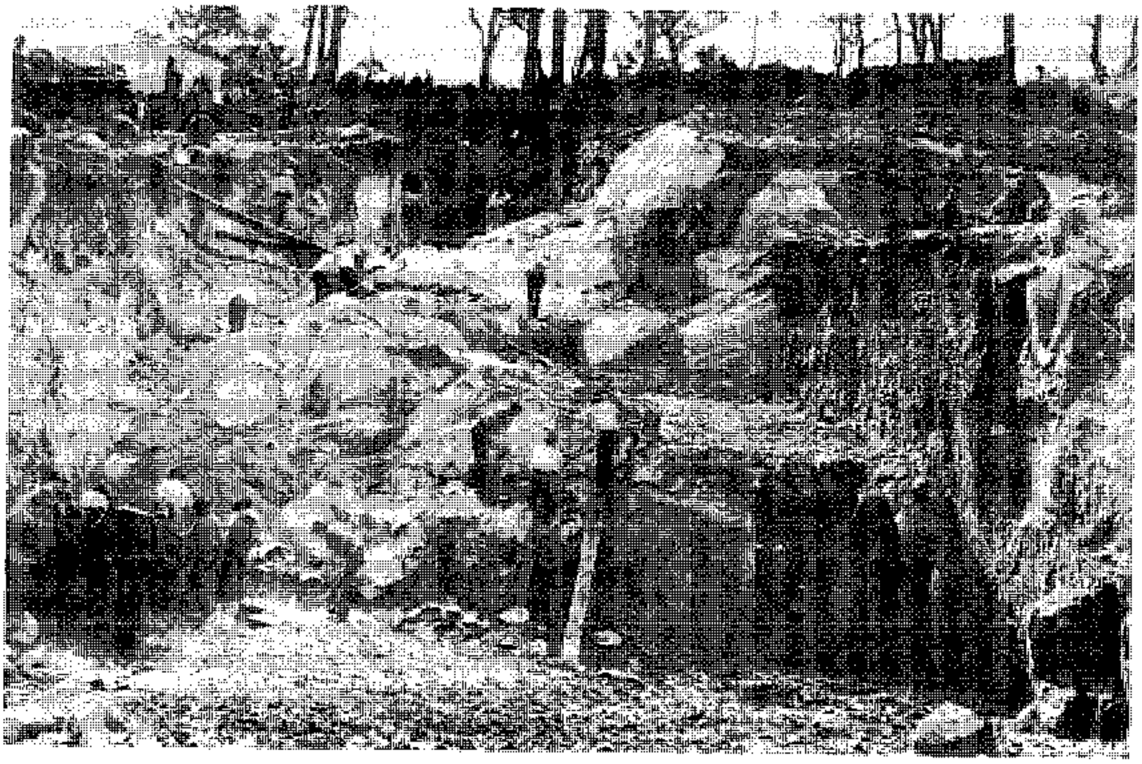
MILES 100 75 50 25 0 100 200 300 400 500 MILES



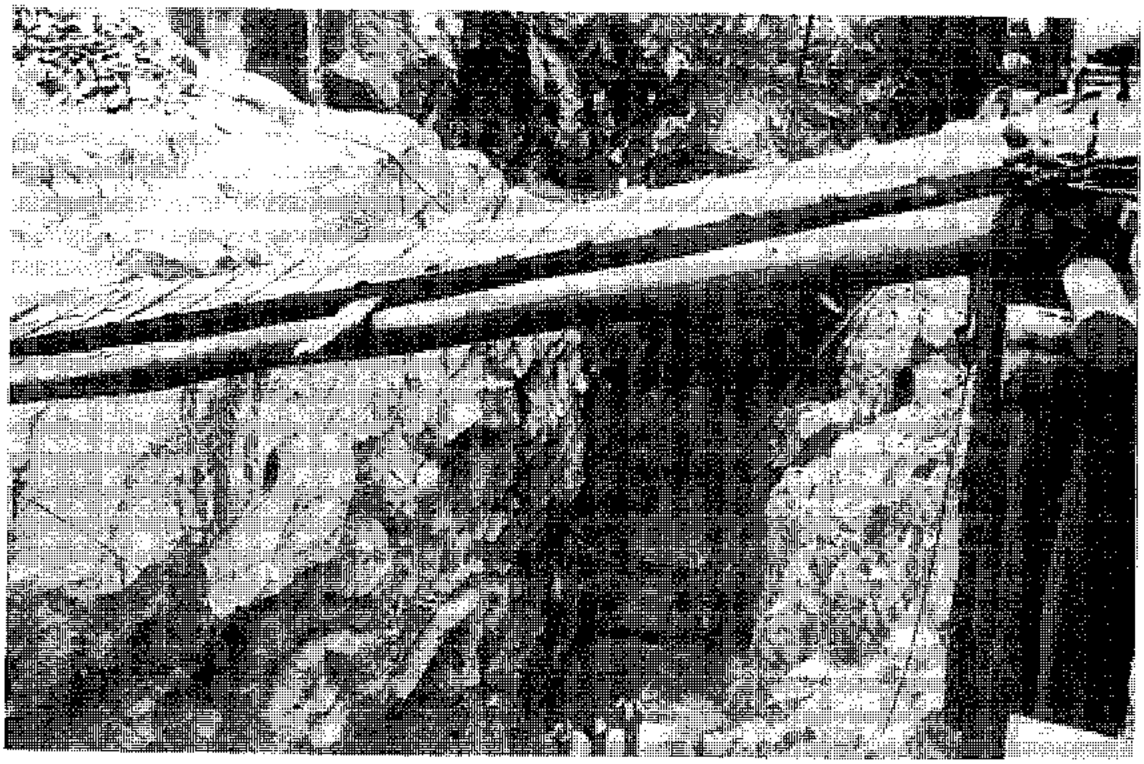
The weir site looking upstream, towards the concrete diversion dam



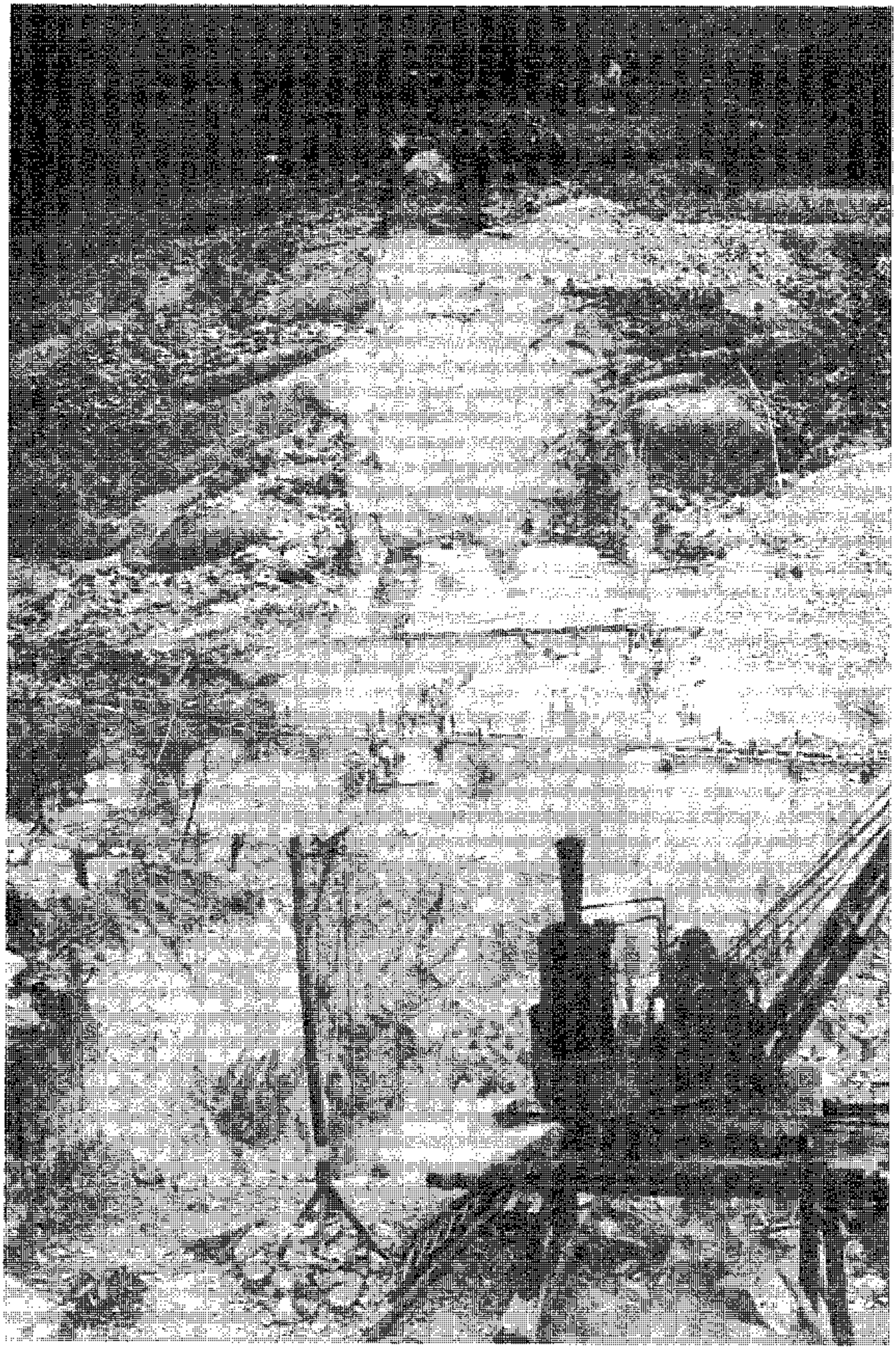
The timber diversion flume



Hand excavation on the right bank

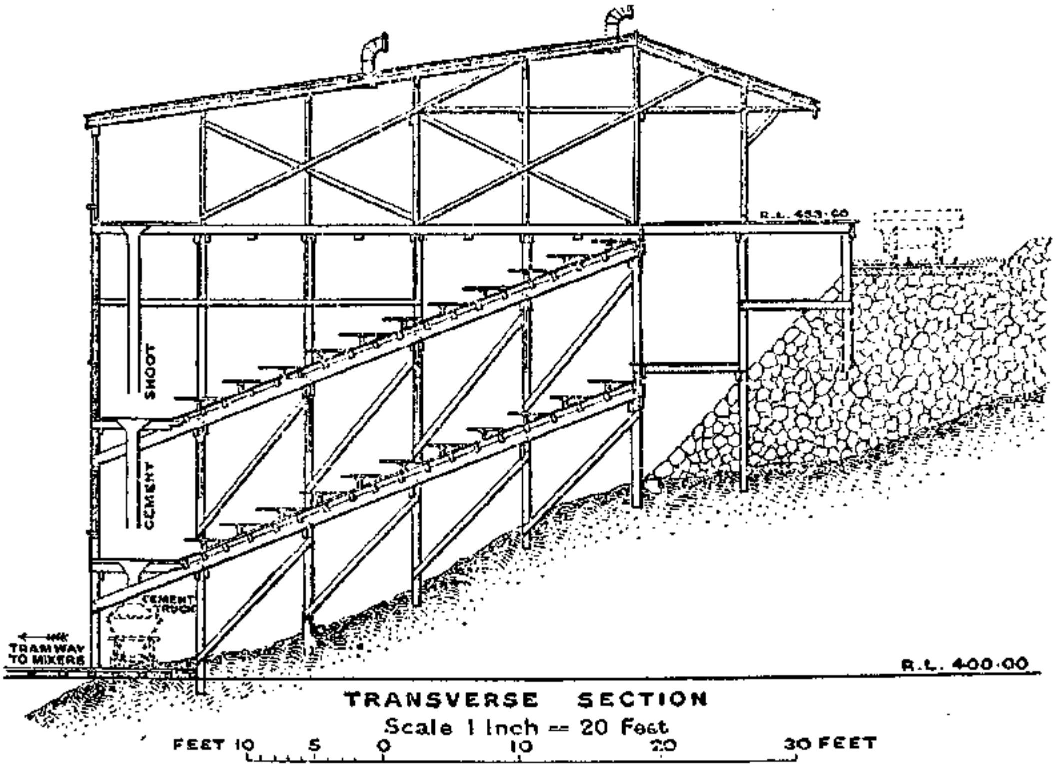


Excavation was taken down to a depth of 90 feet below the river bed

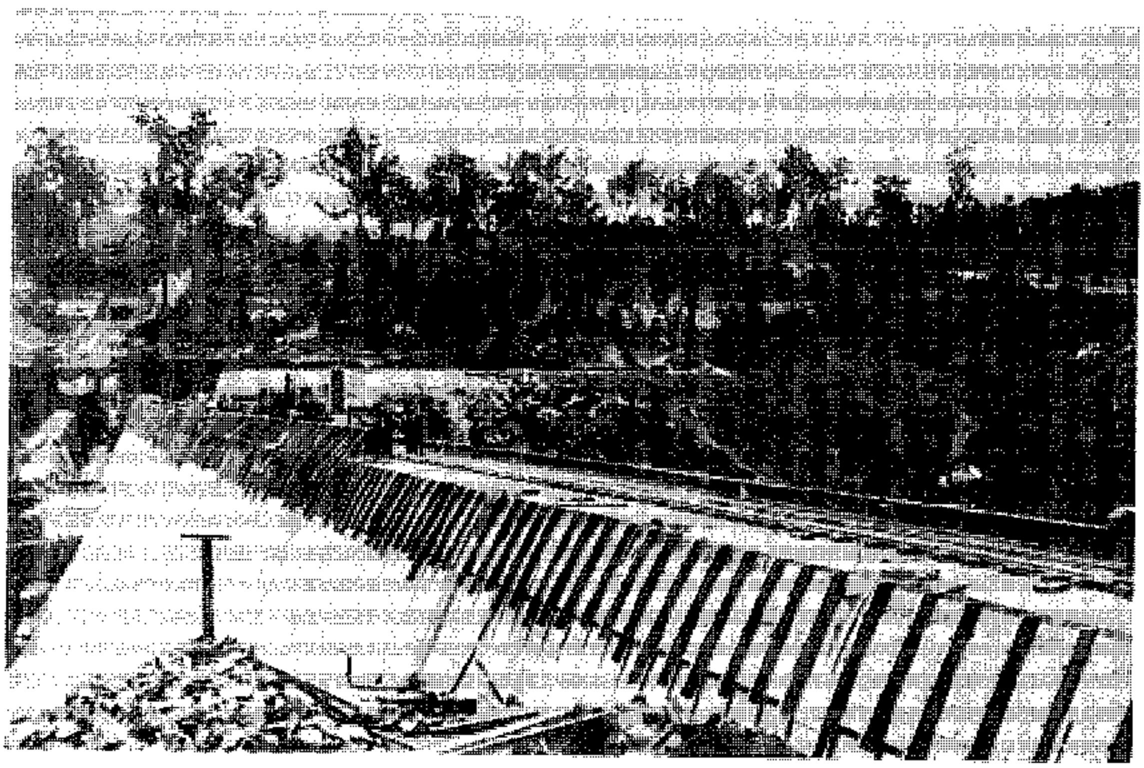


Foundation excavation

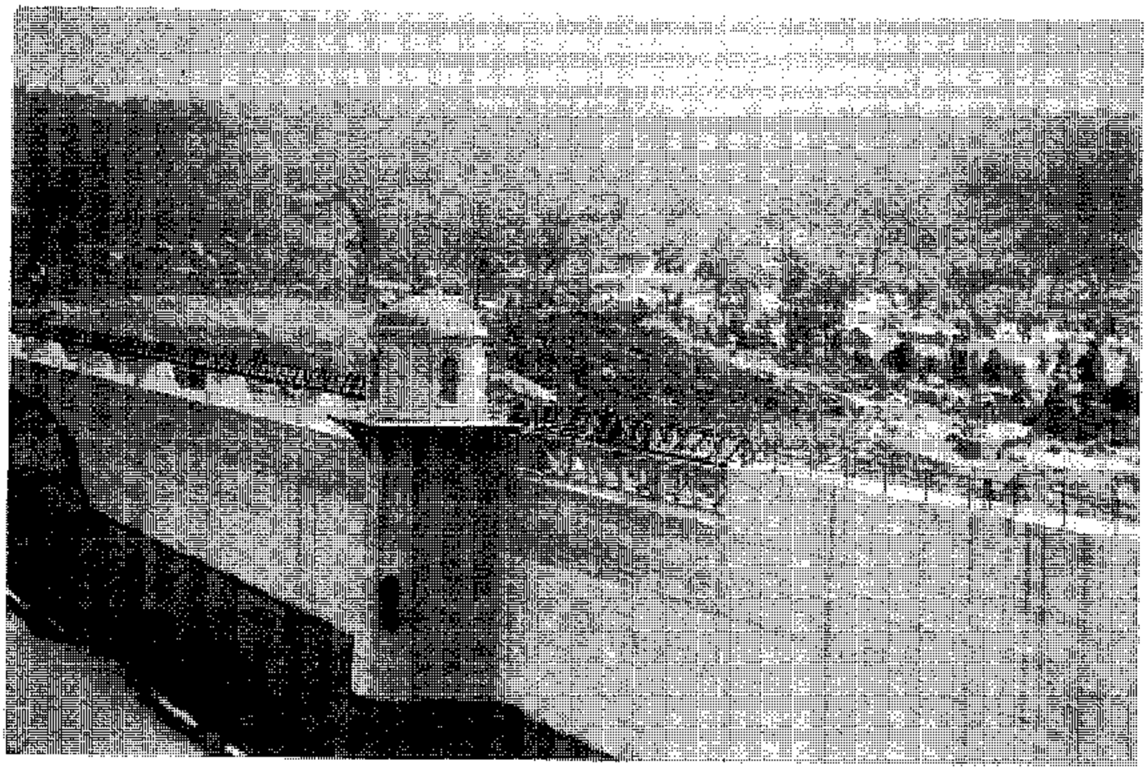
A travelling steam crane was used to handle the concreting skips. The cement slaking shed is on the right abutment



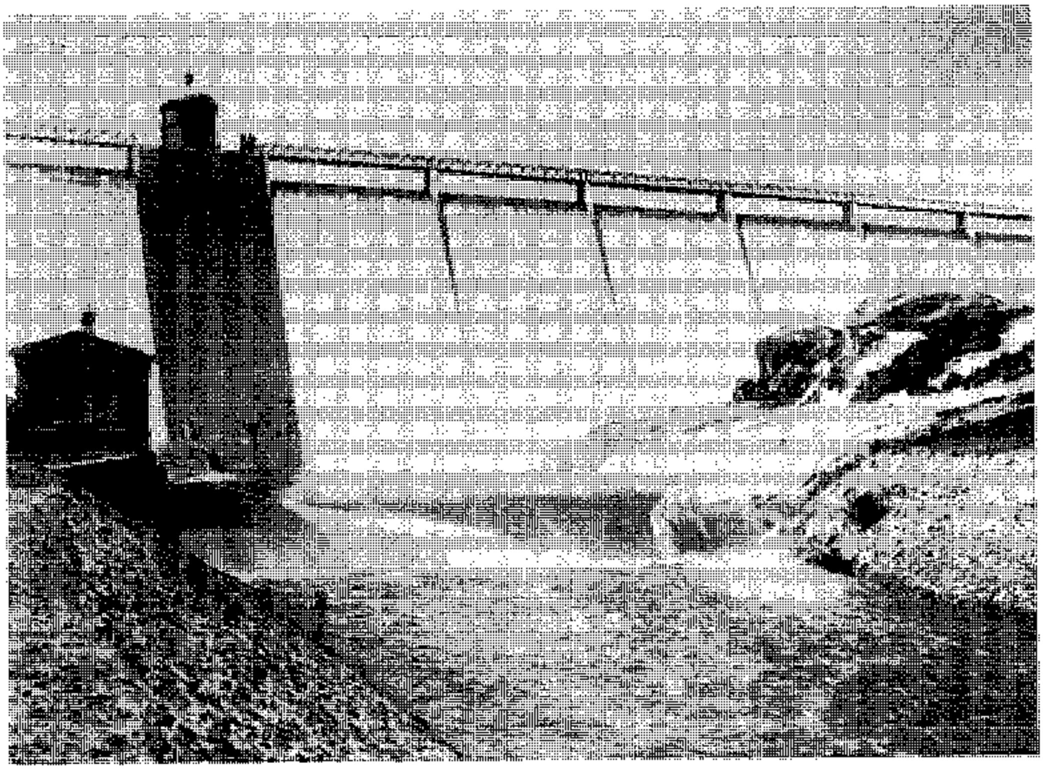
The receiving and slaking shed for the cement



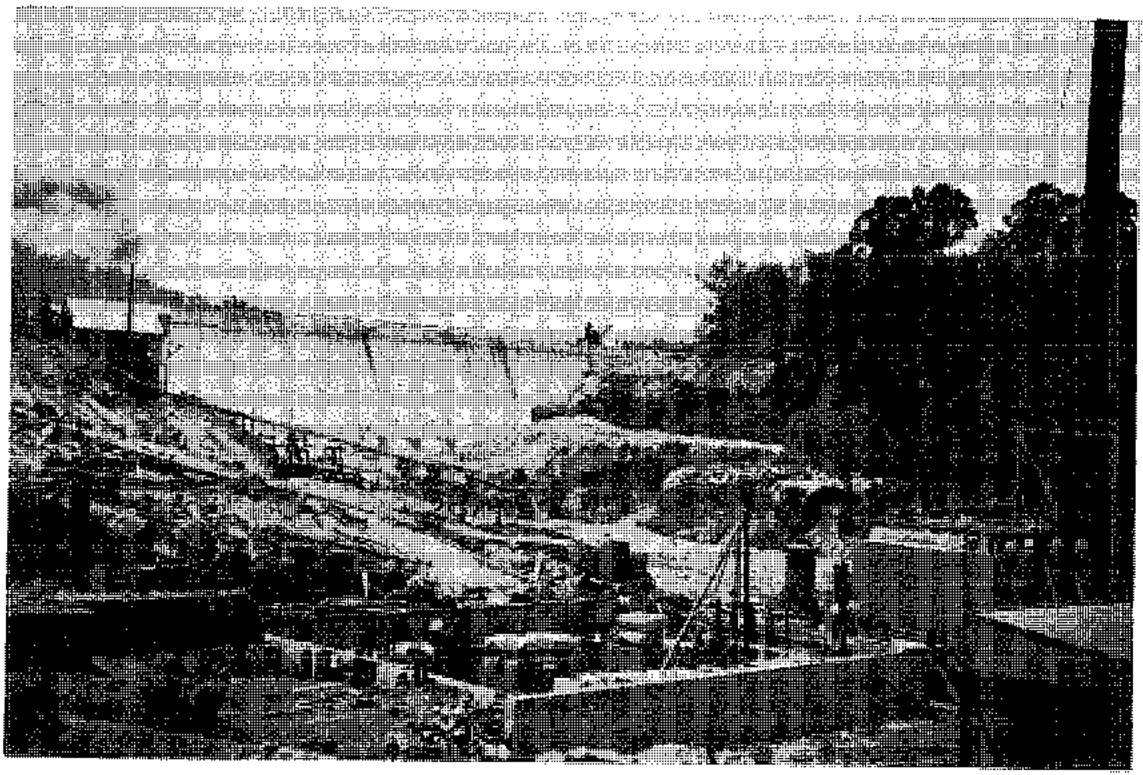
Construction at an advanced stage



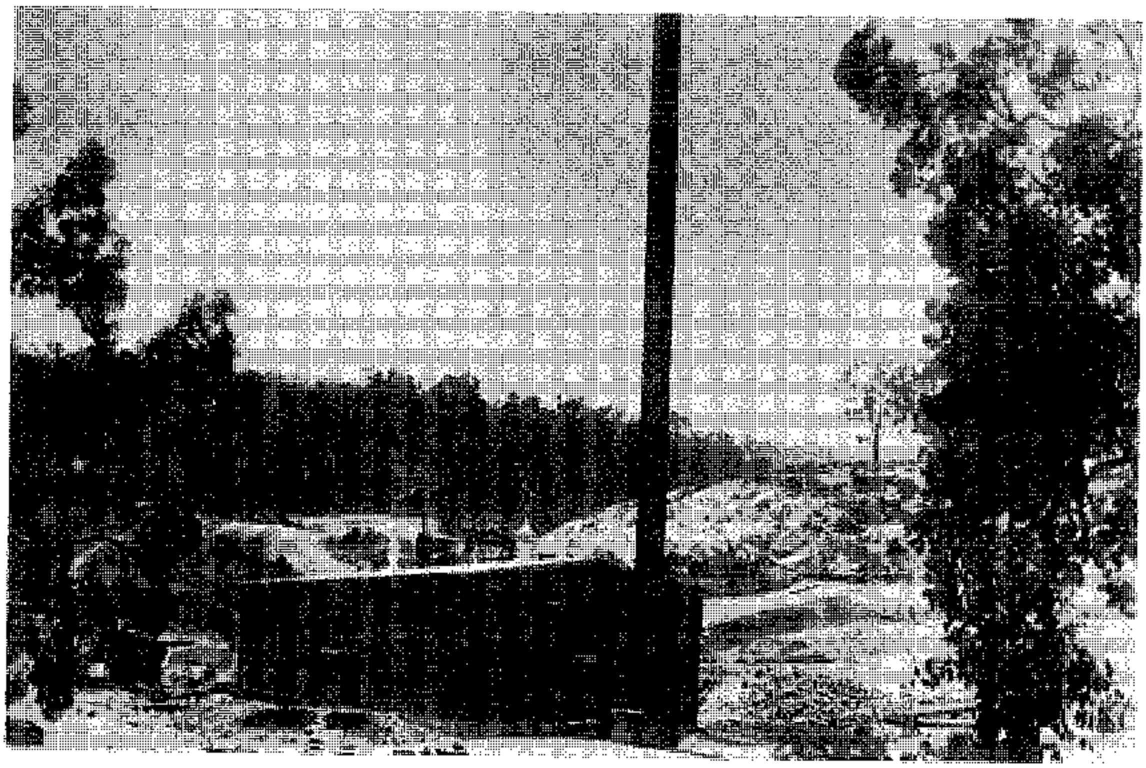
Upstream face and valve tower



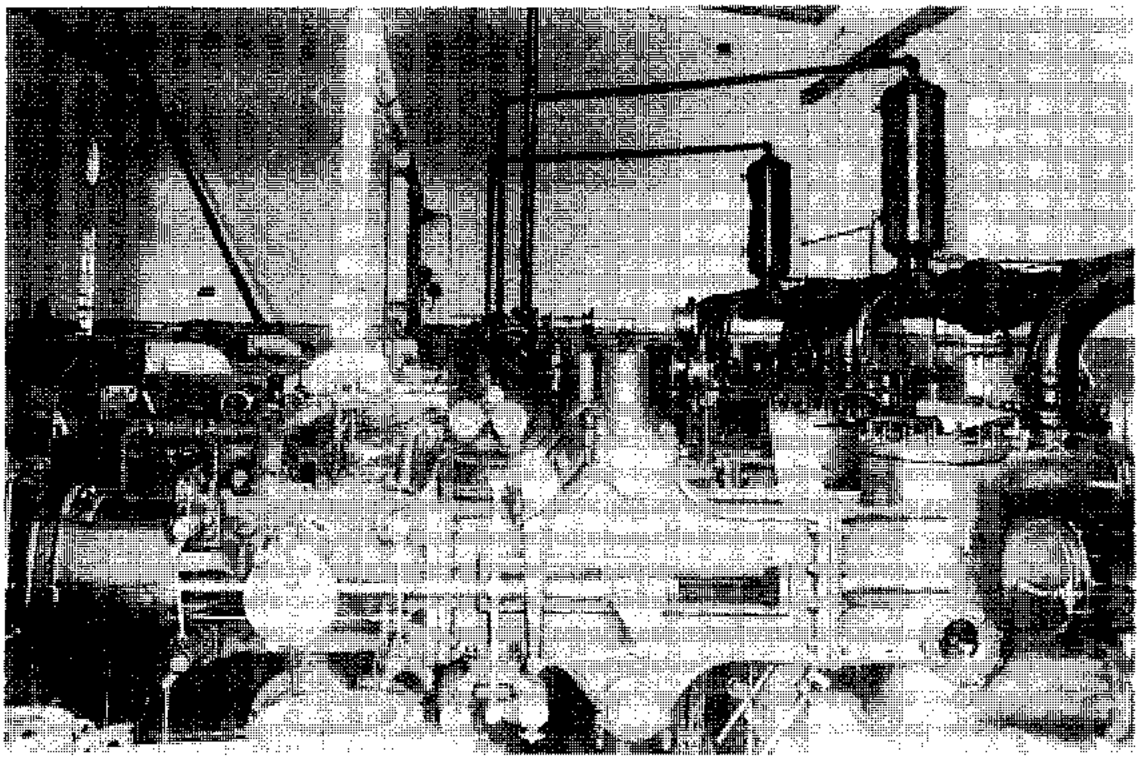
The completed weir



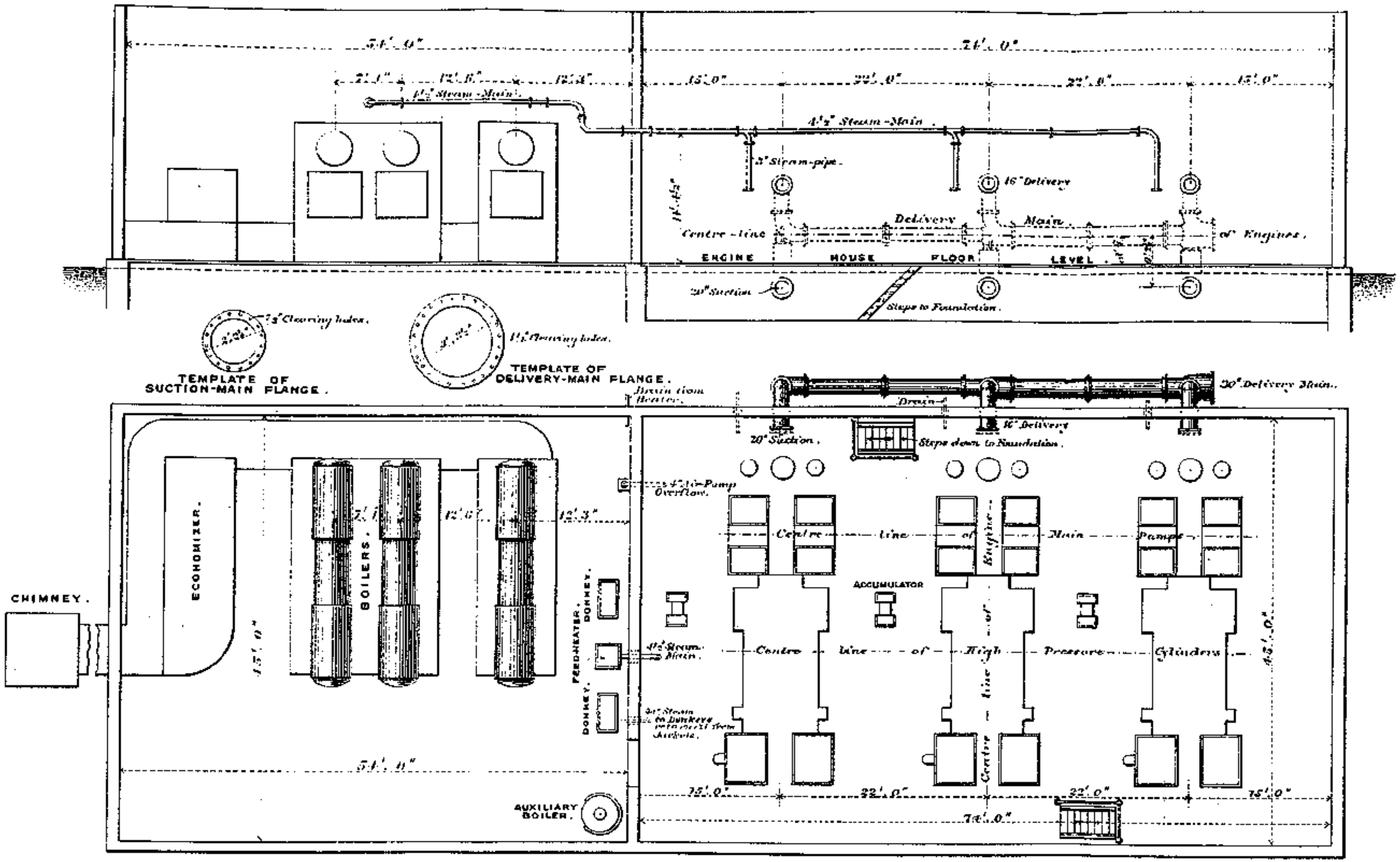
Foundations of Pump Station No. 1



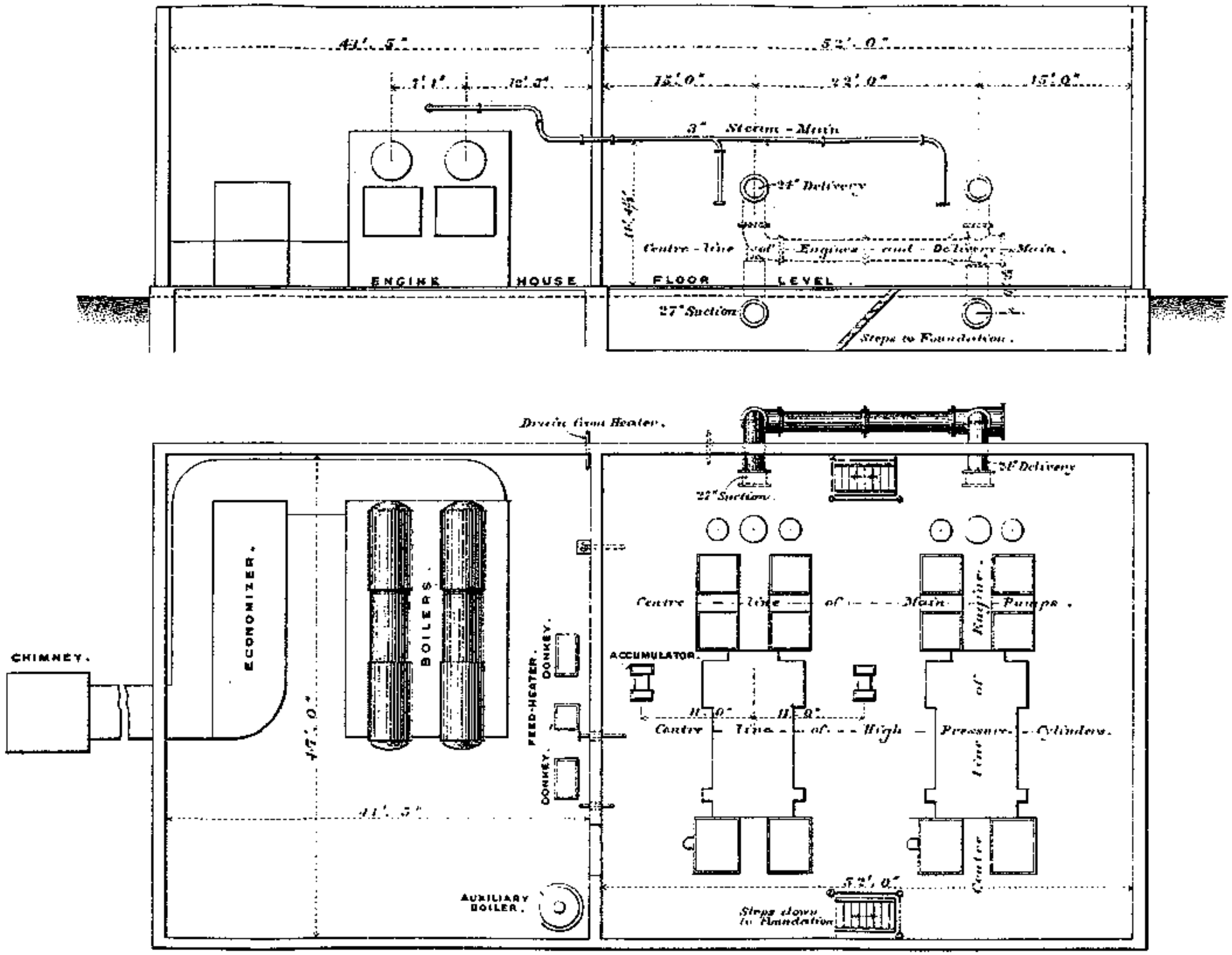
Pump Station No. 1



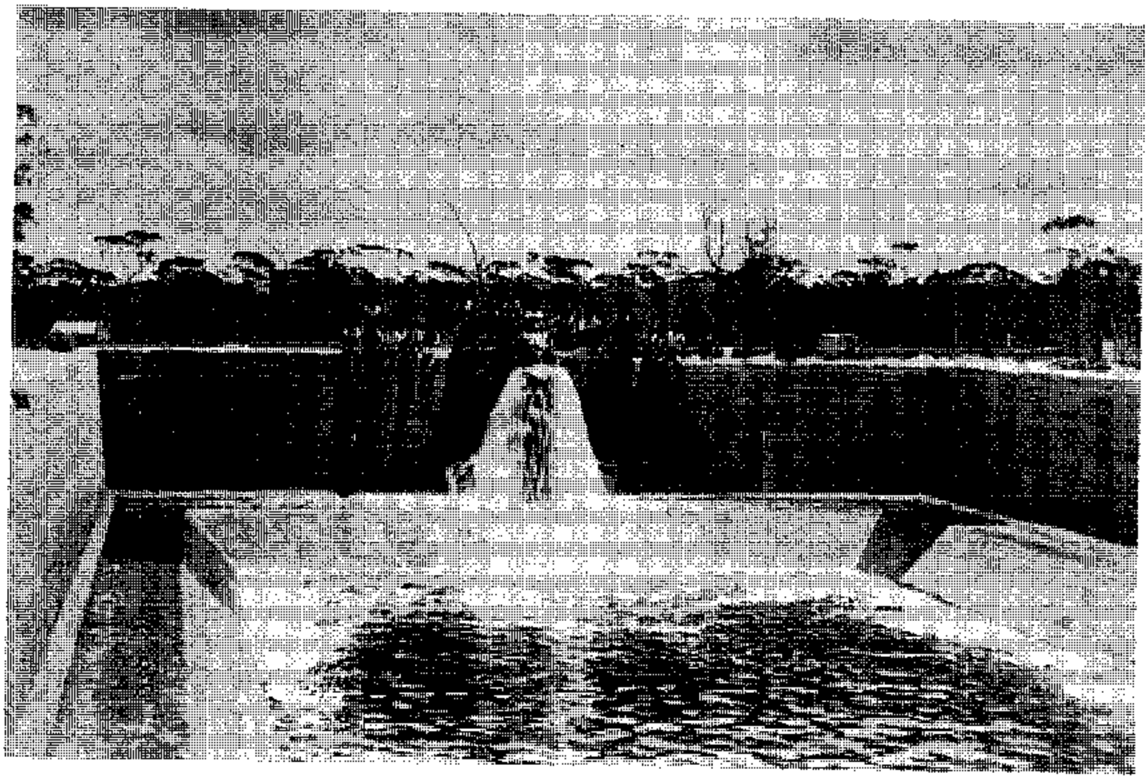
Pump Station No. 1: Six cylinder triple expansion pumping engines



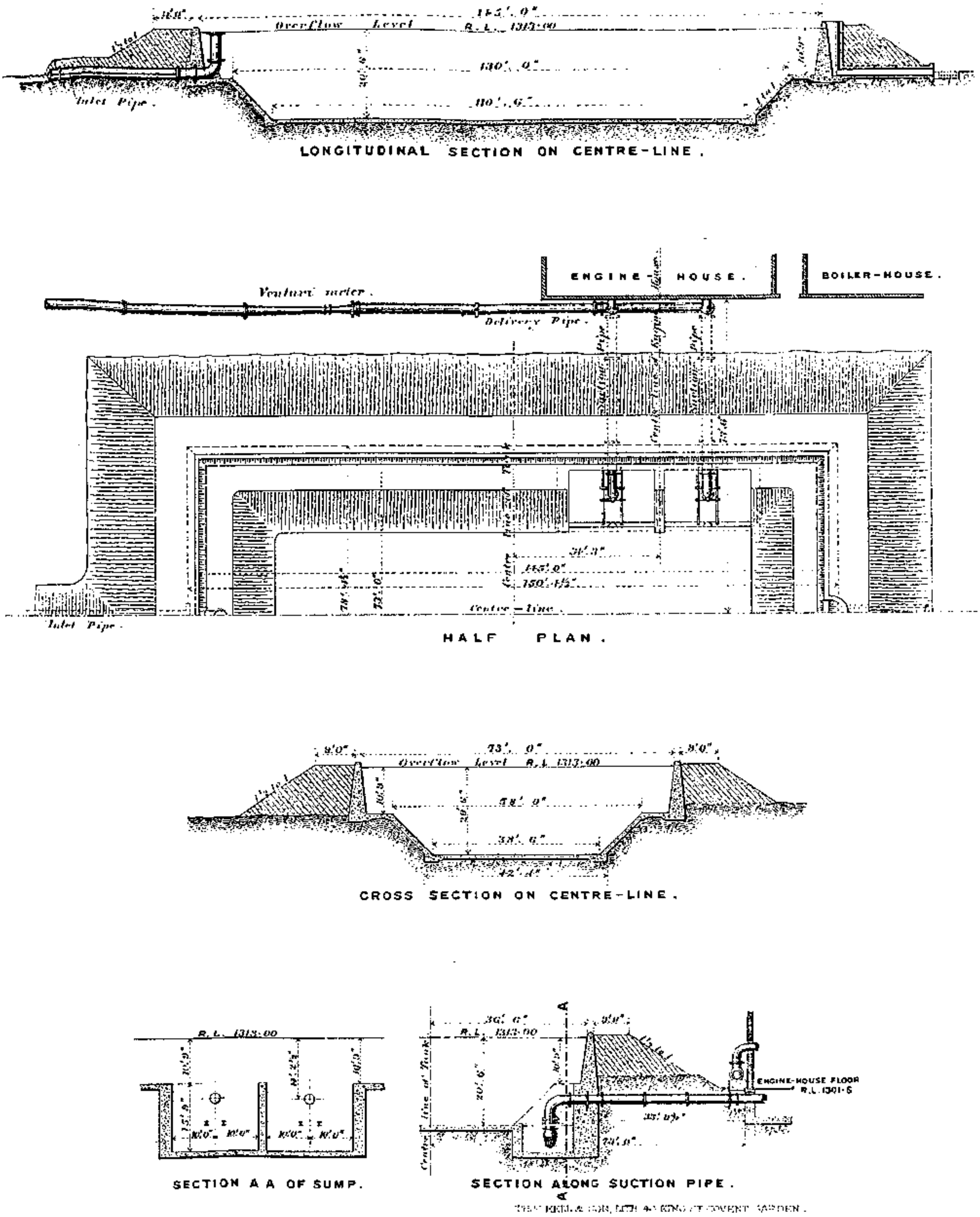
General arrangement: Three pump-set station



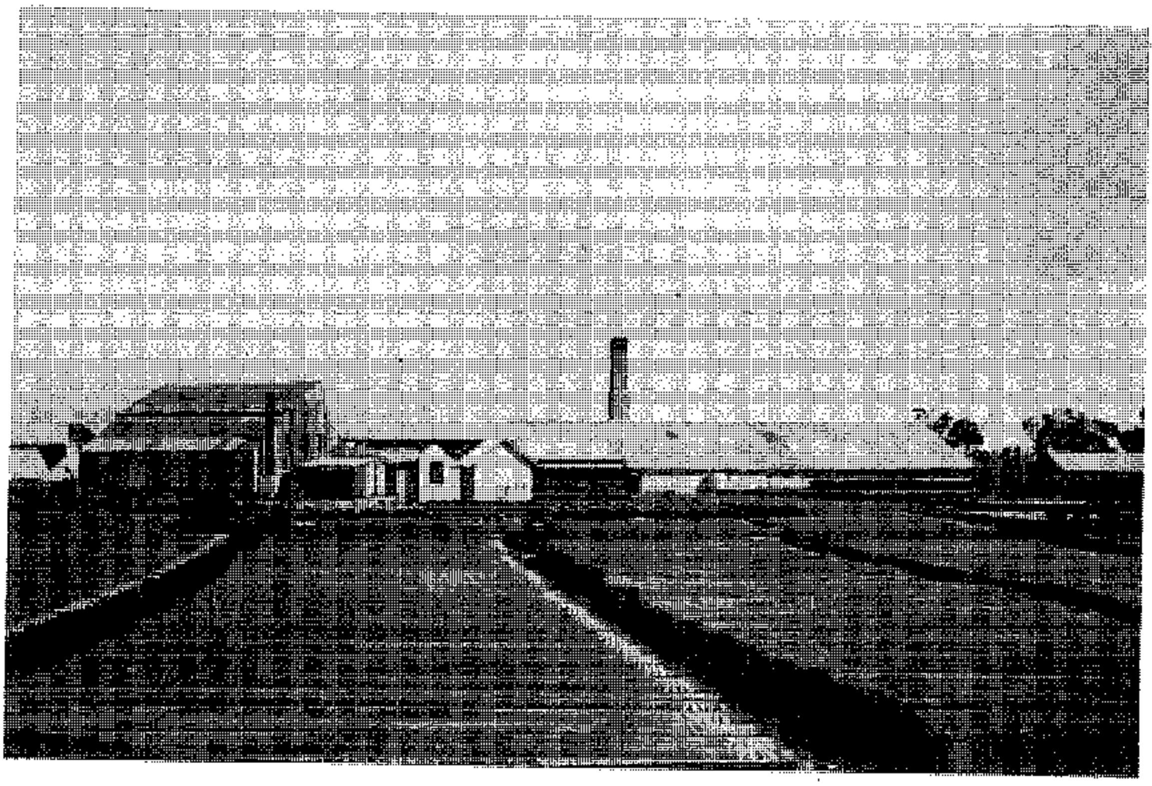
General arrangement: Two pump-set station



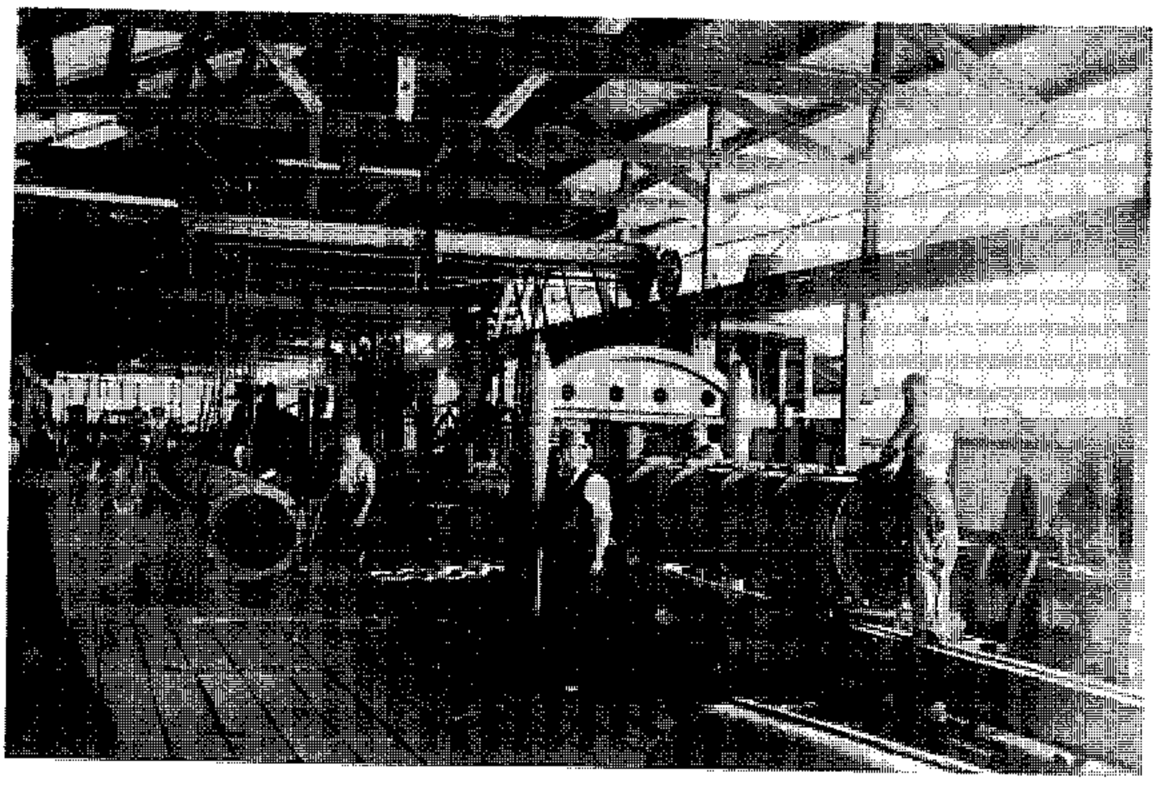
First filling of a typical receiving and suction-tank



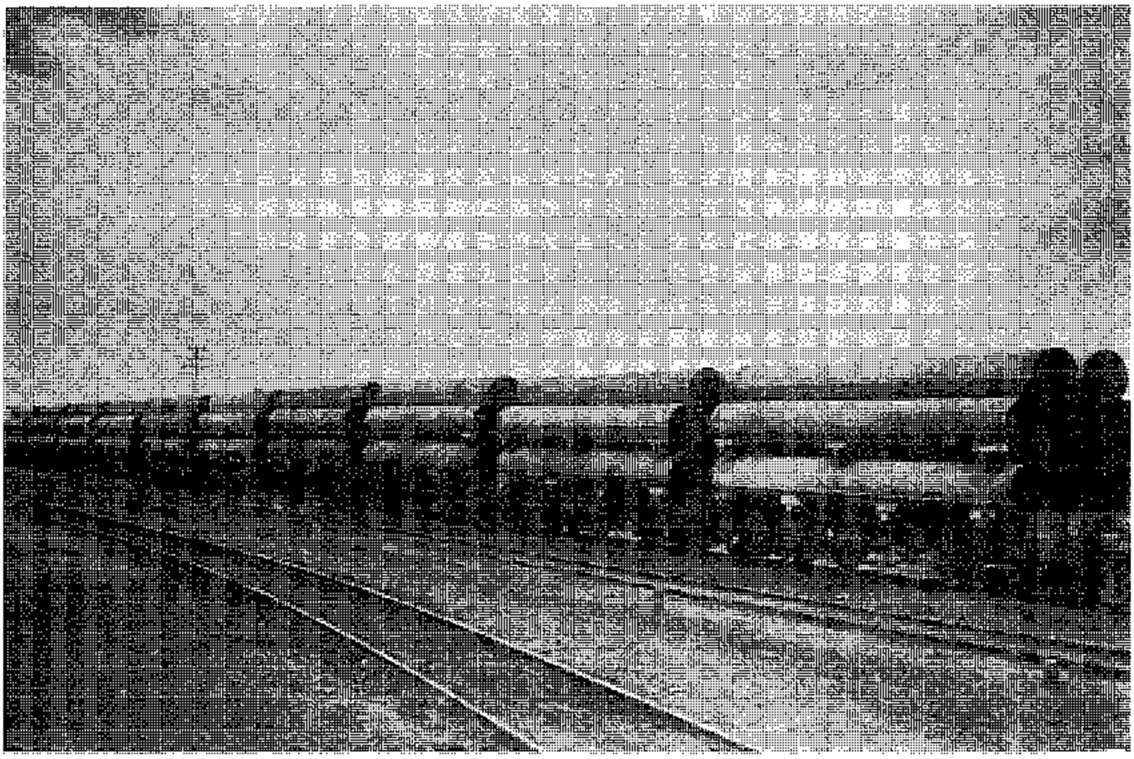
General arrangement of a concrete-lined suction tank



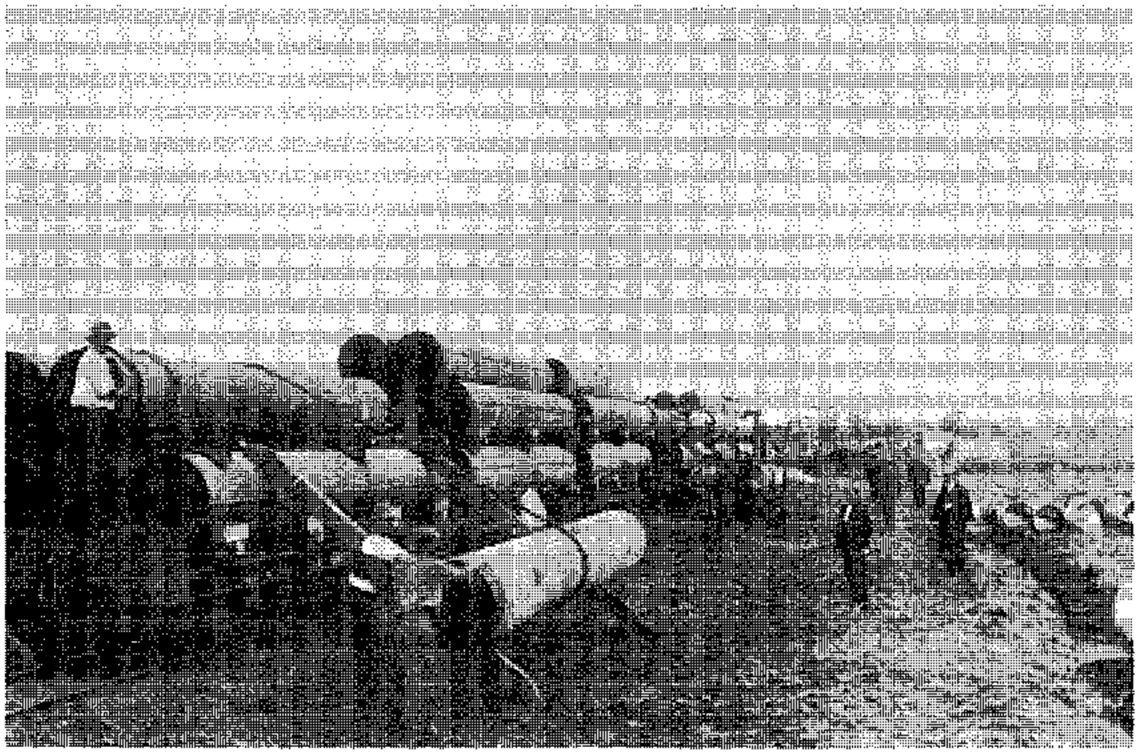
Completed locking-bar pipes at the Perth Works



Locking-bar pipe works



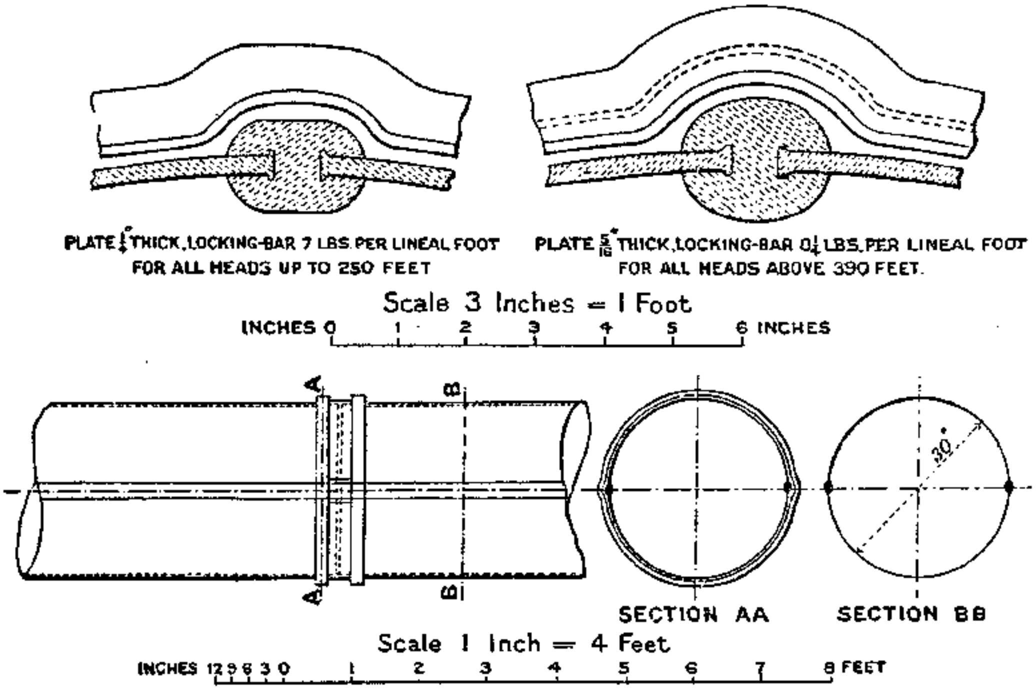
A route for the pipeline was deliberately chosen close to the goldfields railway



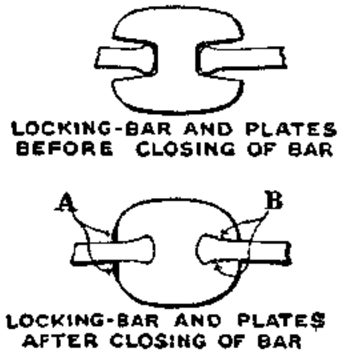
The pipe trains had to be unloaded quickly to avoid holding up other rail traffic on the single line

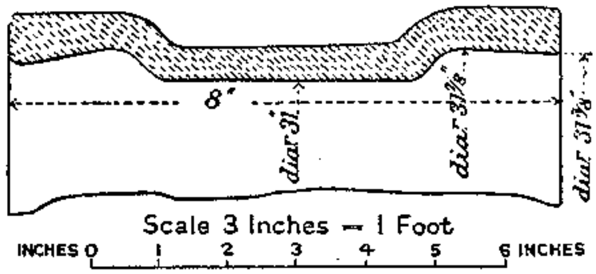
Trench excavation in forested country

There were numerous gulley crossings

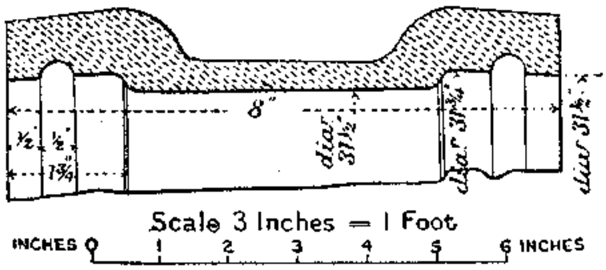


A typical sleeve joint



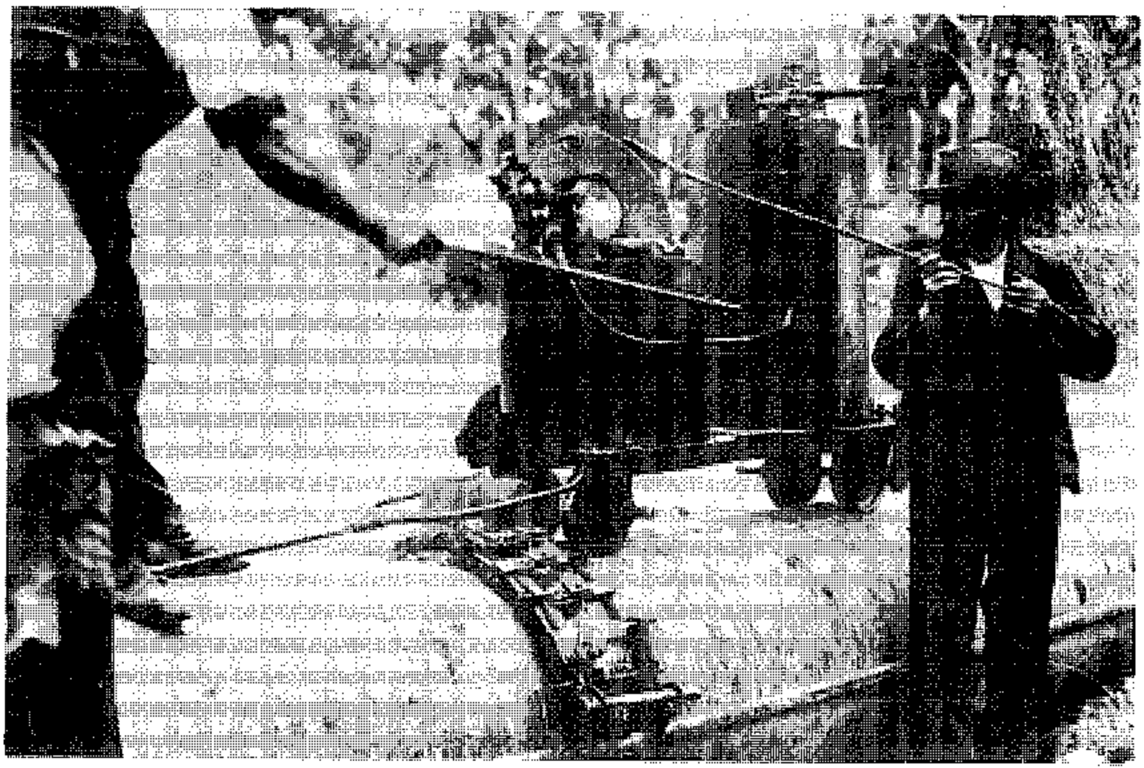


126 lbs joint ring

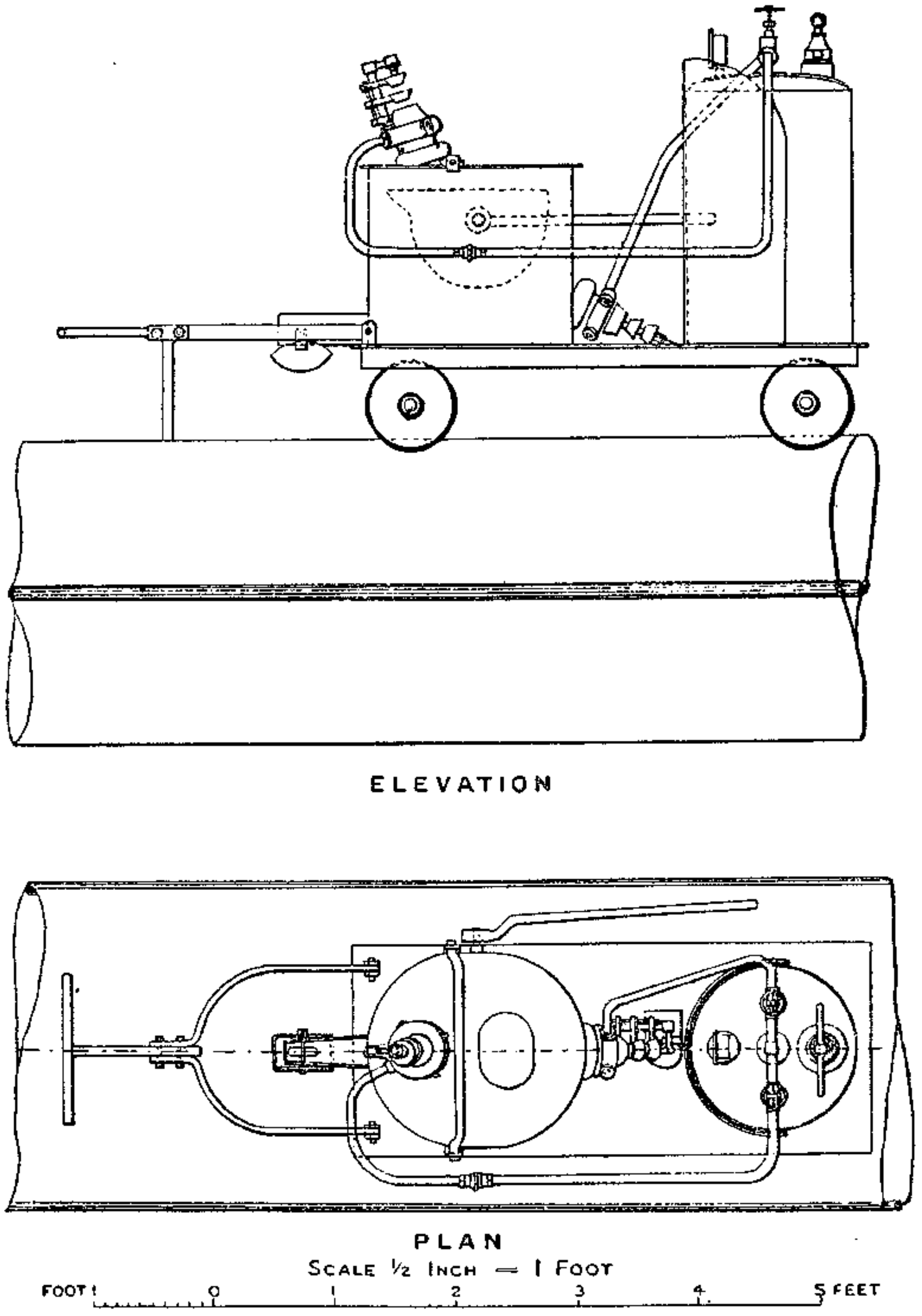


160 lbs joint ring

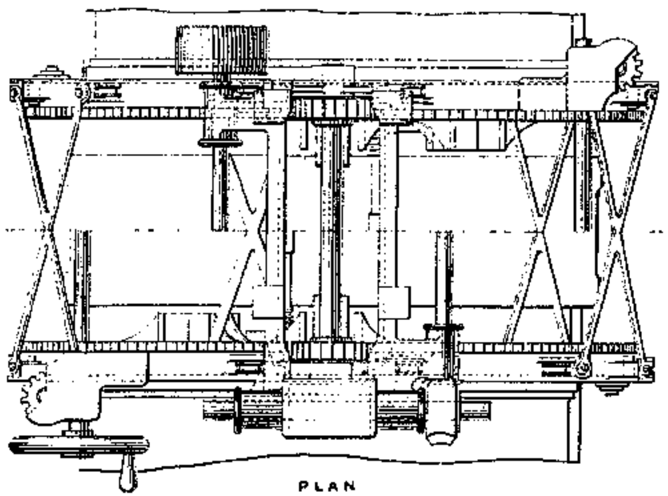
Setting up a joint ring for lead pouring



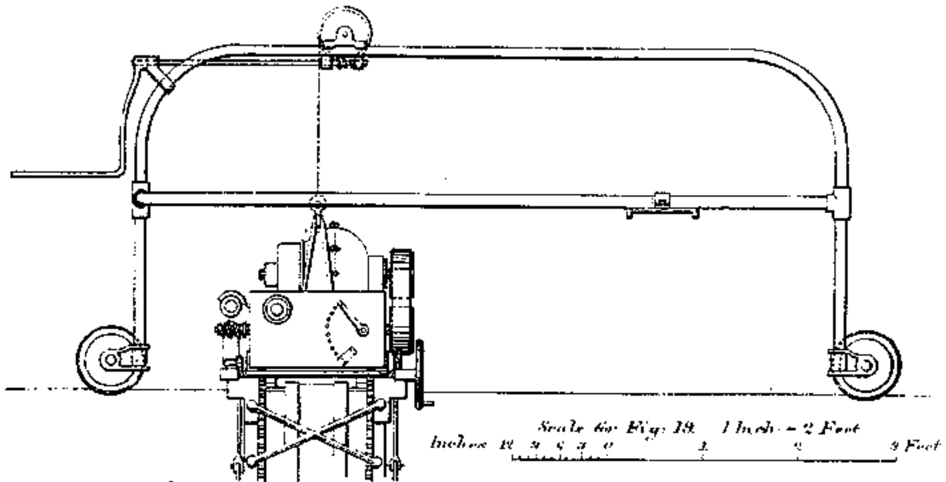
Running a joint with the lead melter



General arrangement of lead-melter

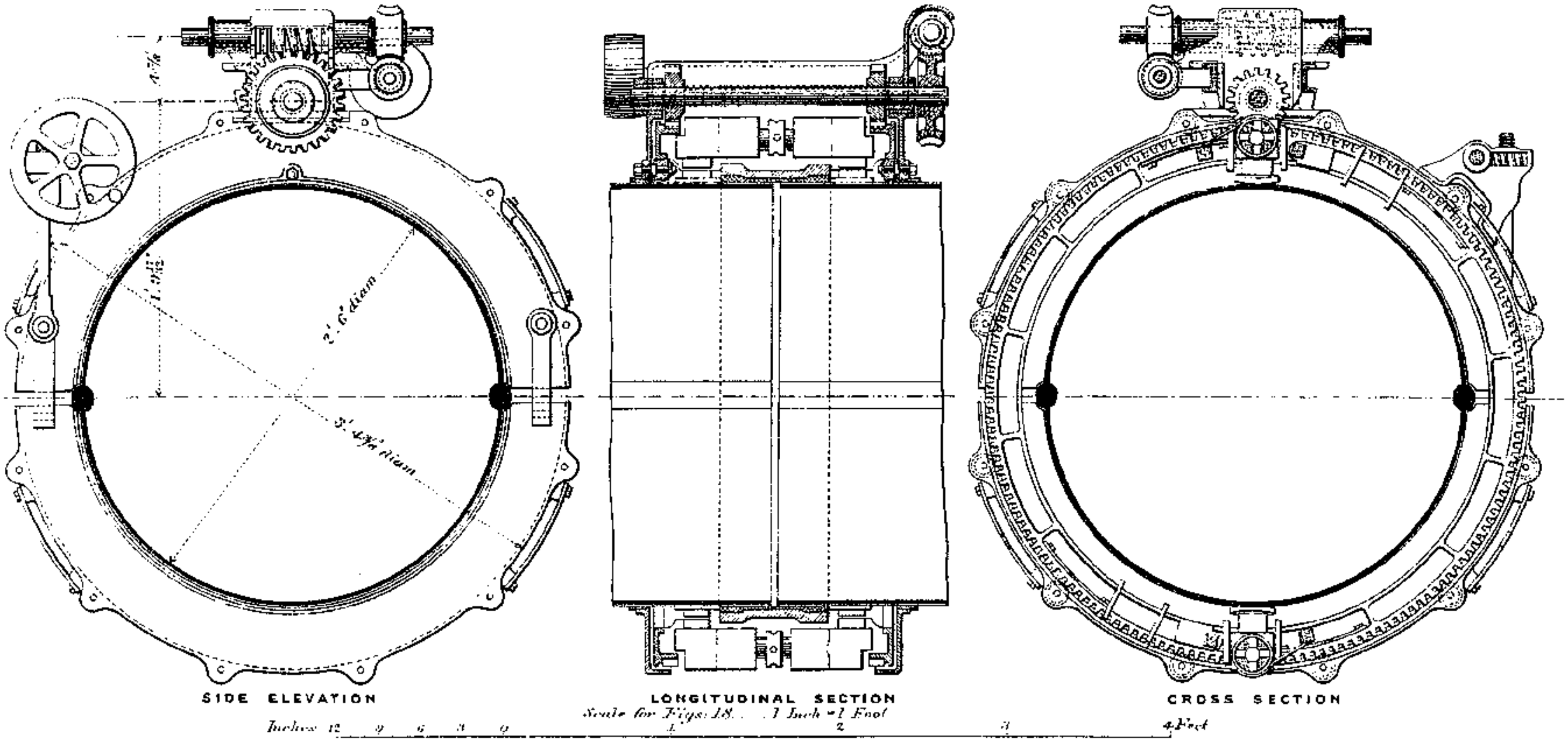


PLAN

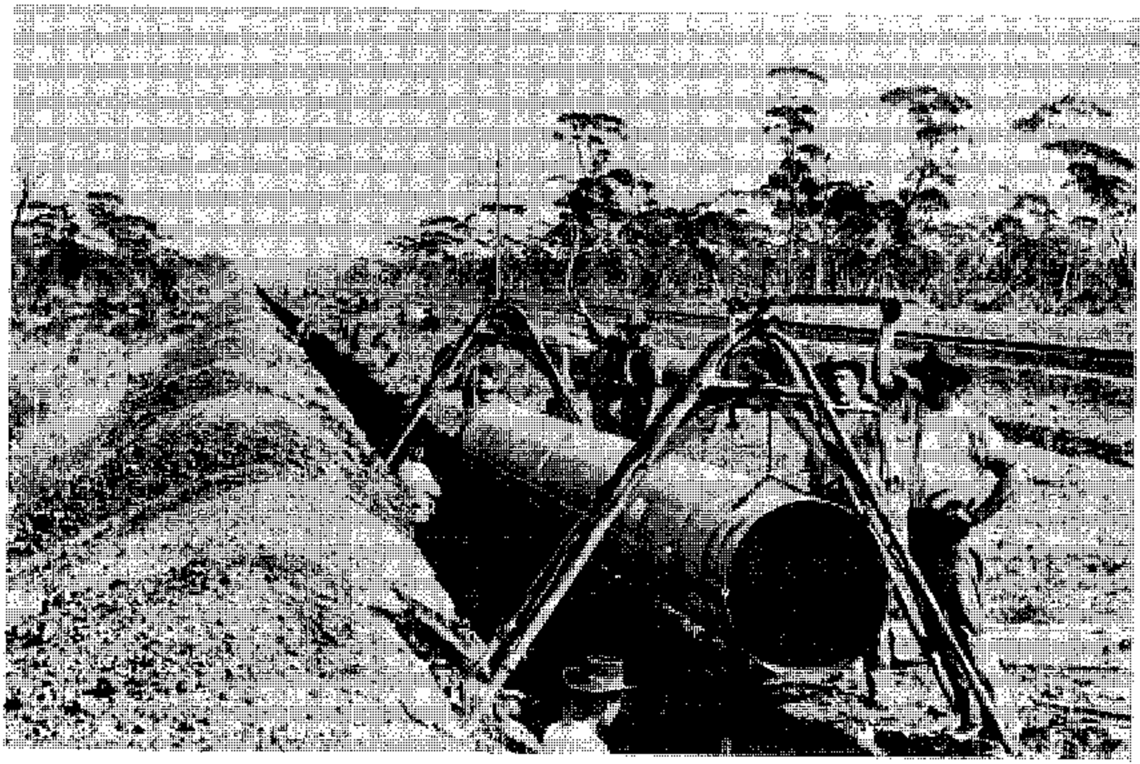


ARRANGEMENT OF MACHINE AND TRANSPORT – CARRIAGE.

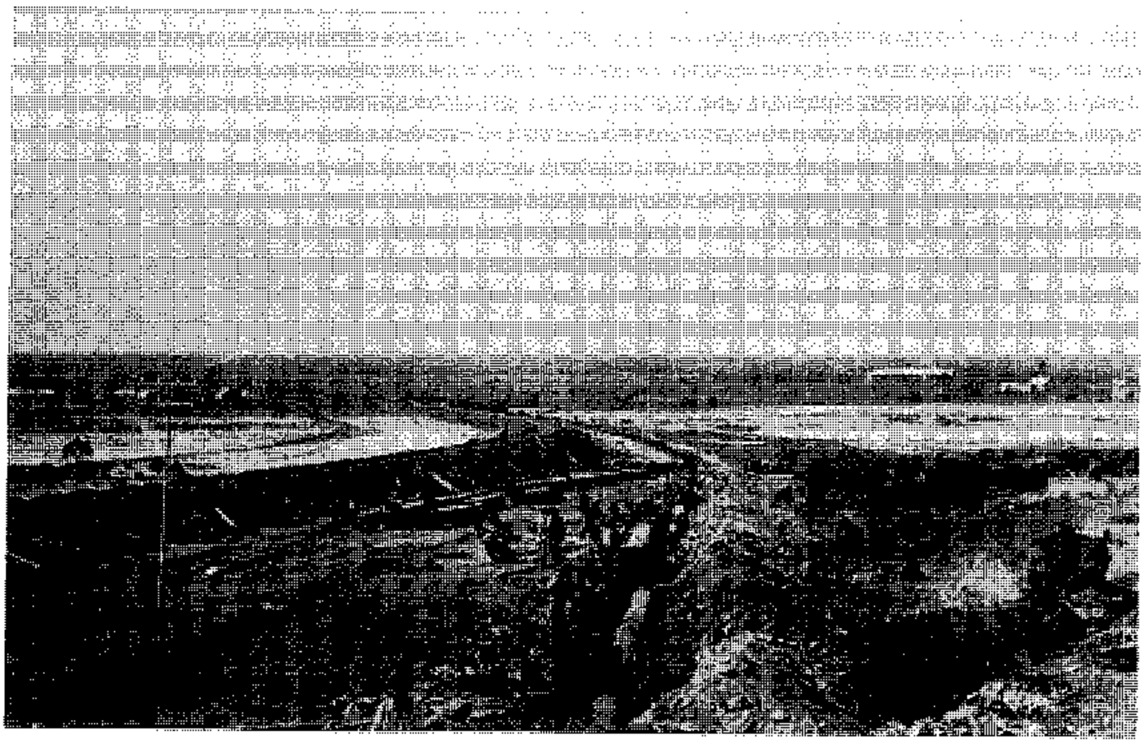
Caulking machine



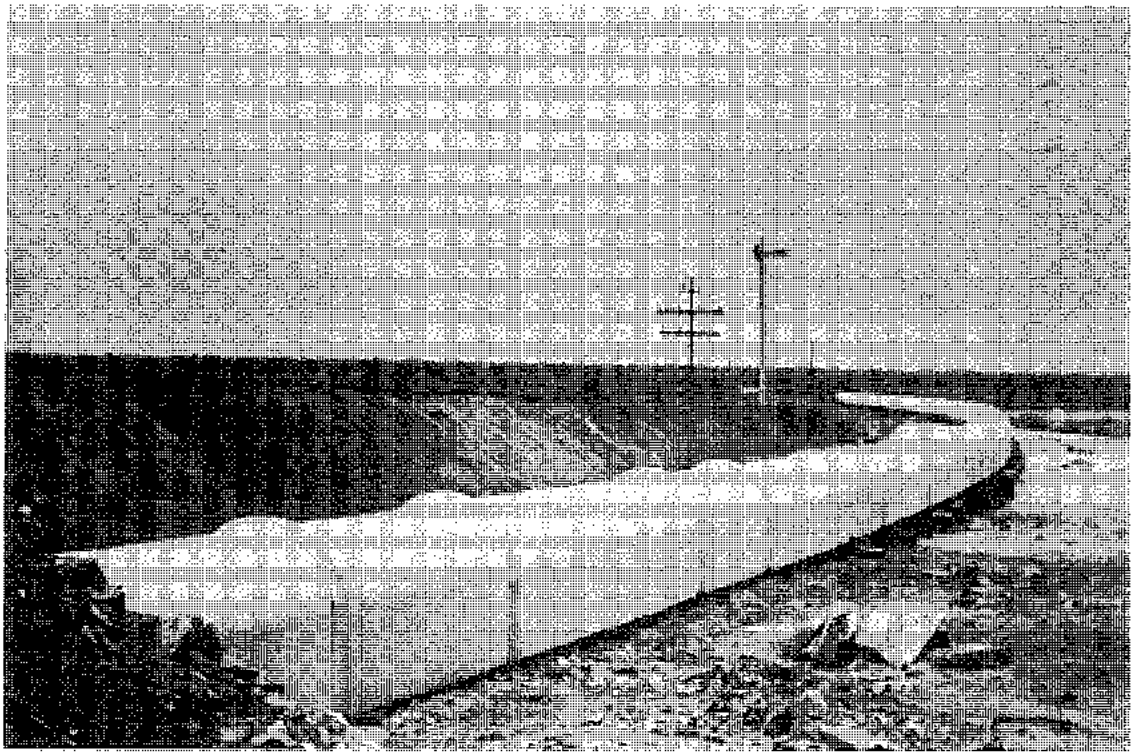
Caulking machine detail



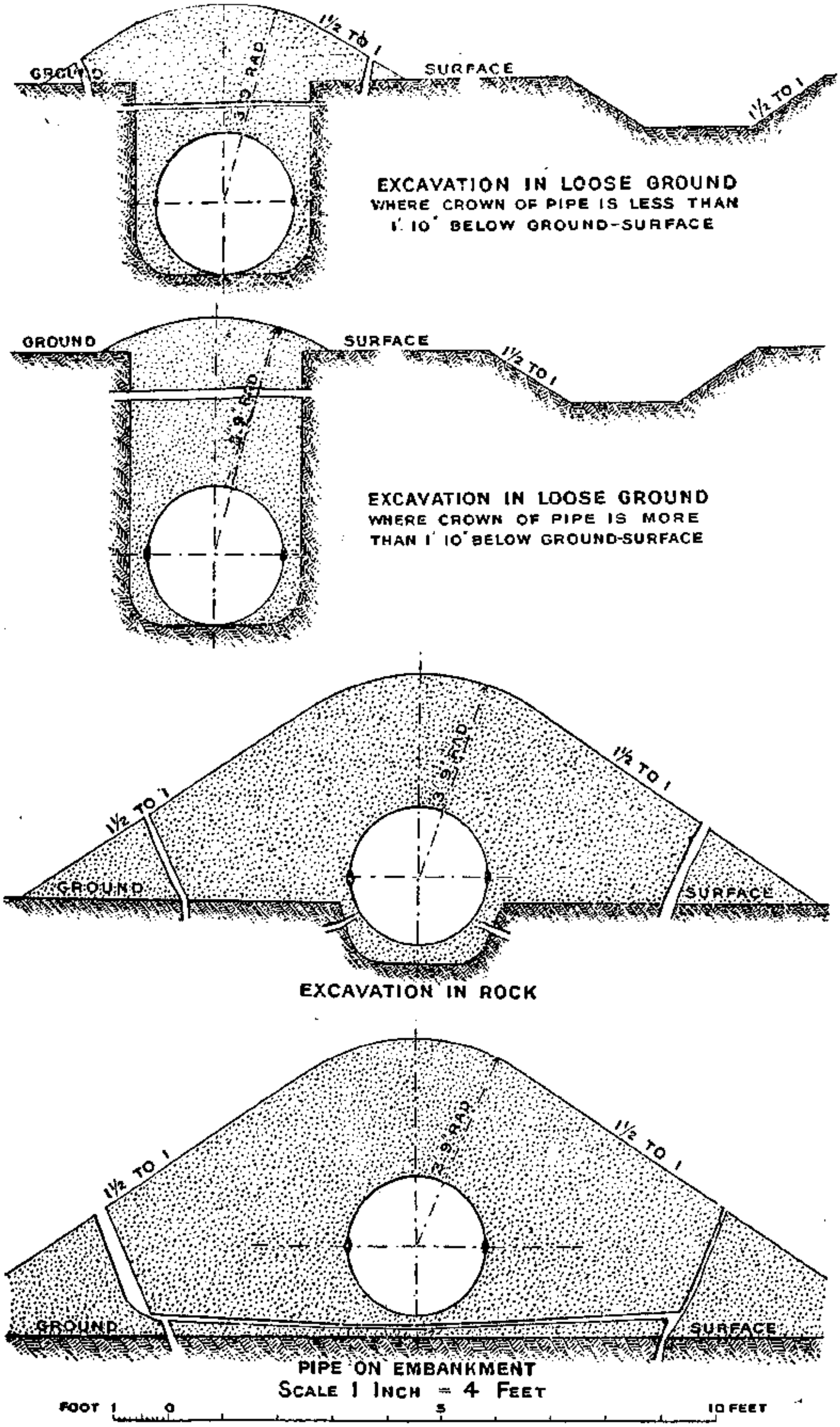
Pipe laying



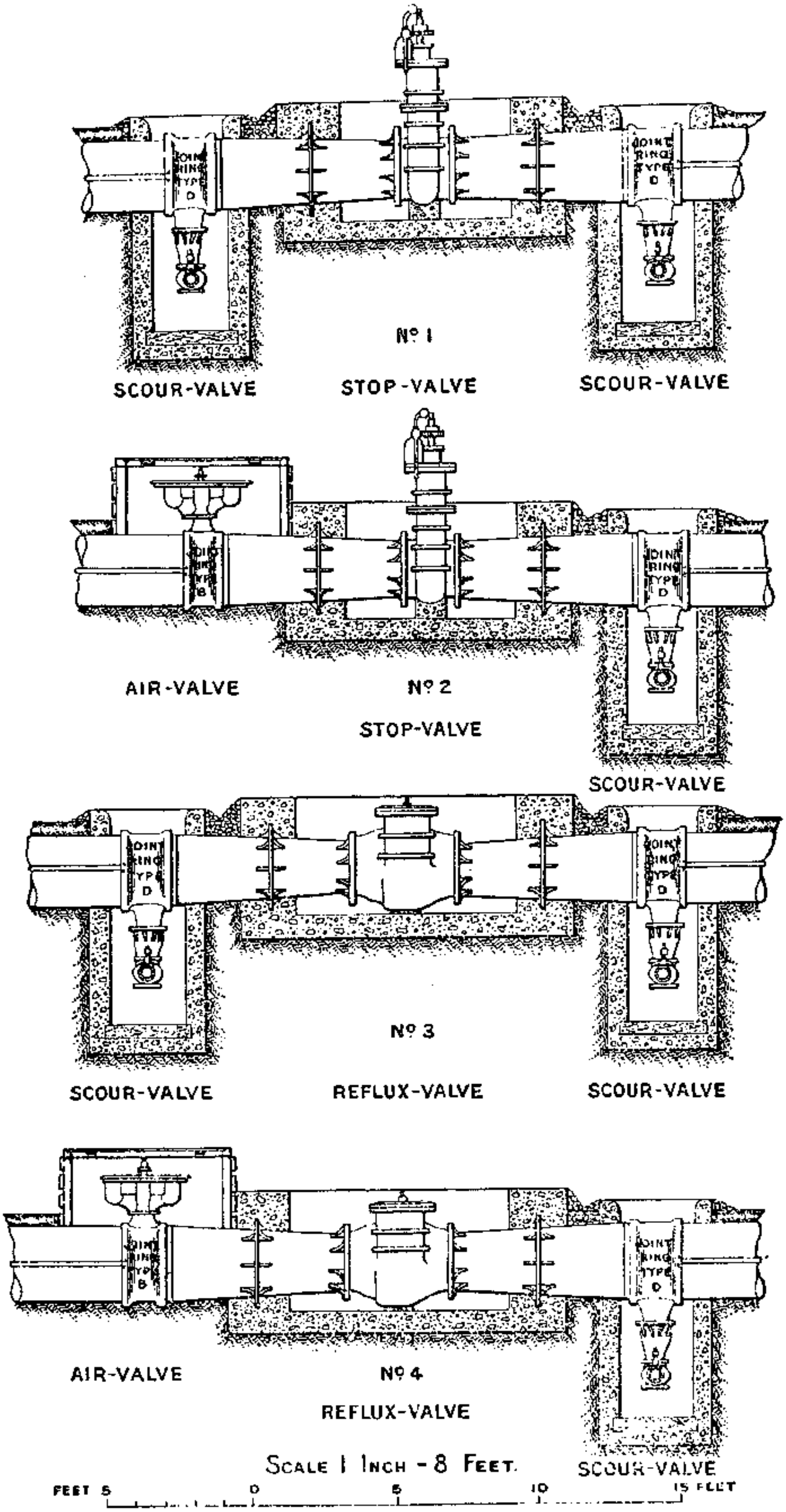
Pipe laying



... and the pipes were surrounded by an insulation of saw dust, kept in place by galvanised corrugated iron



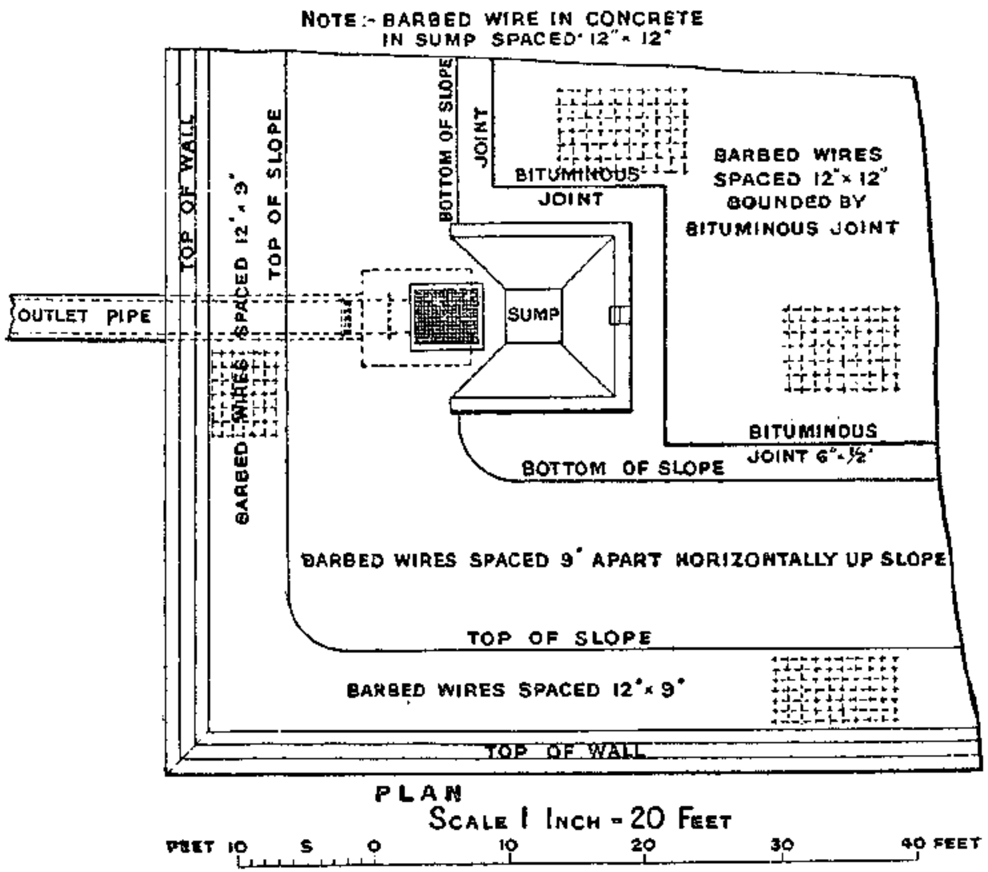
Pipe in cutting and in embankment

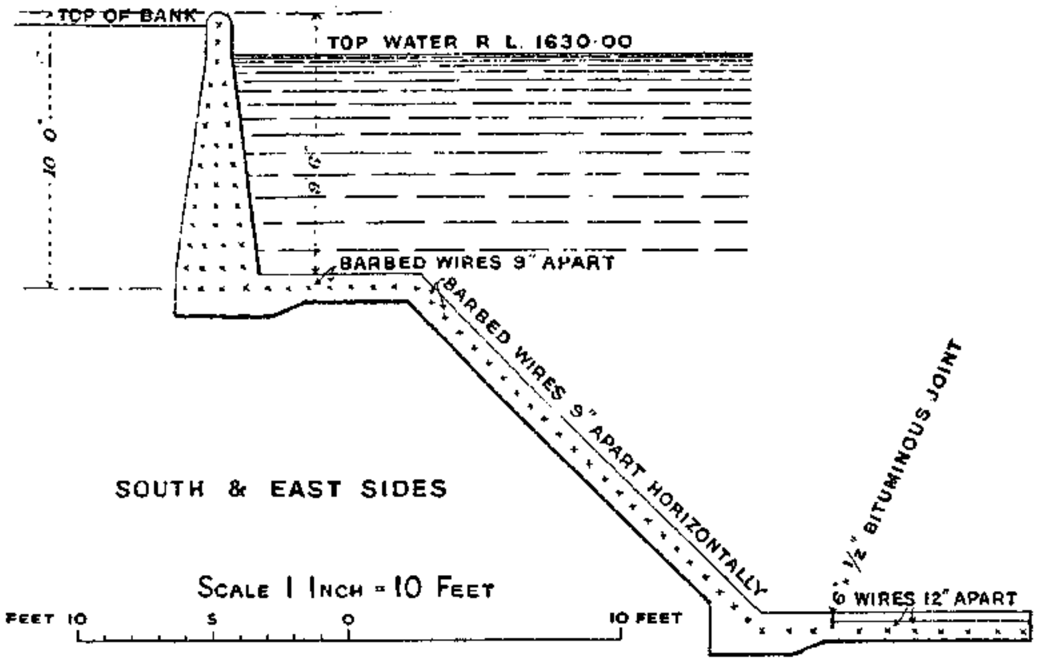


General arrangement of valves

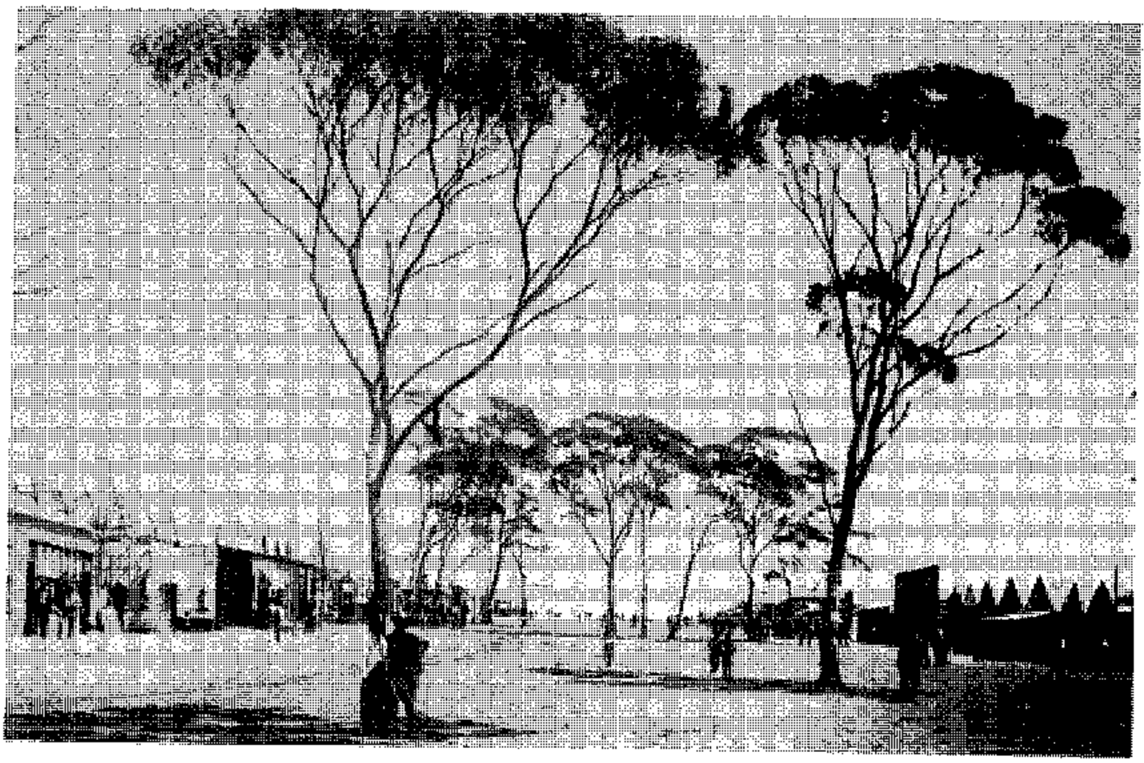
Reservoir construction

Reservoir construction

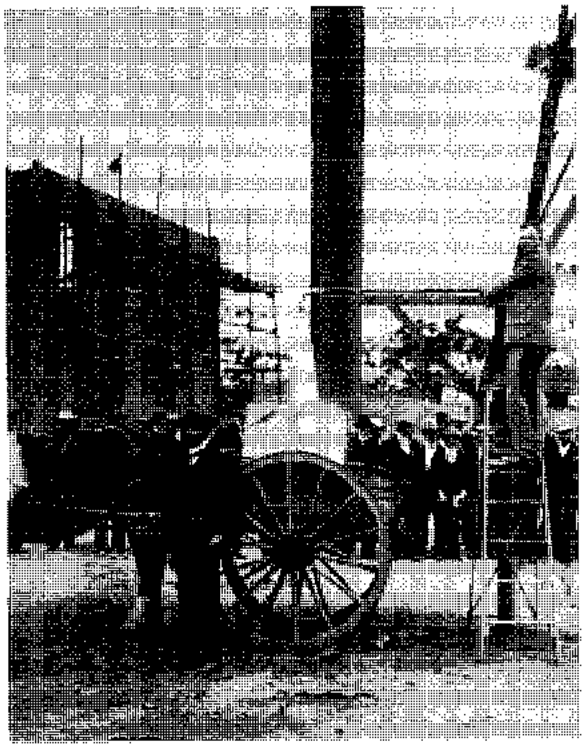




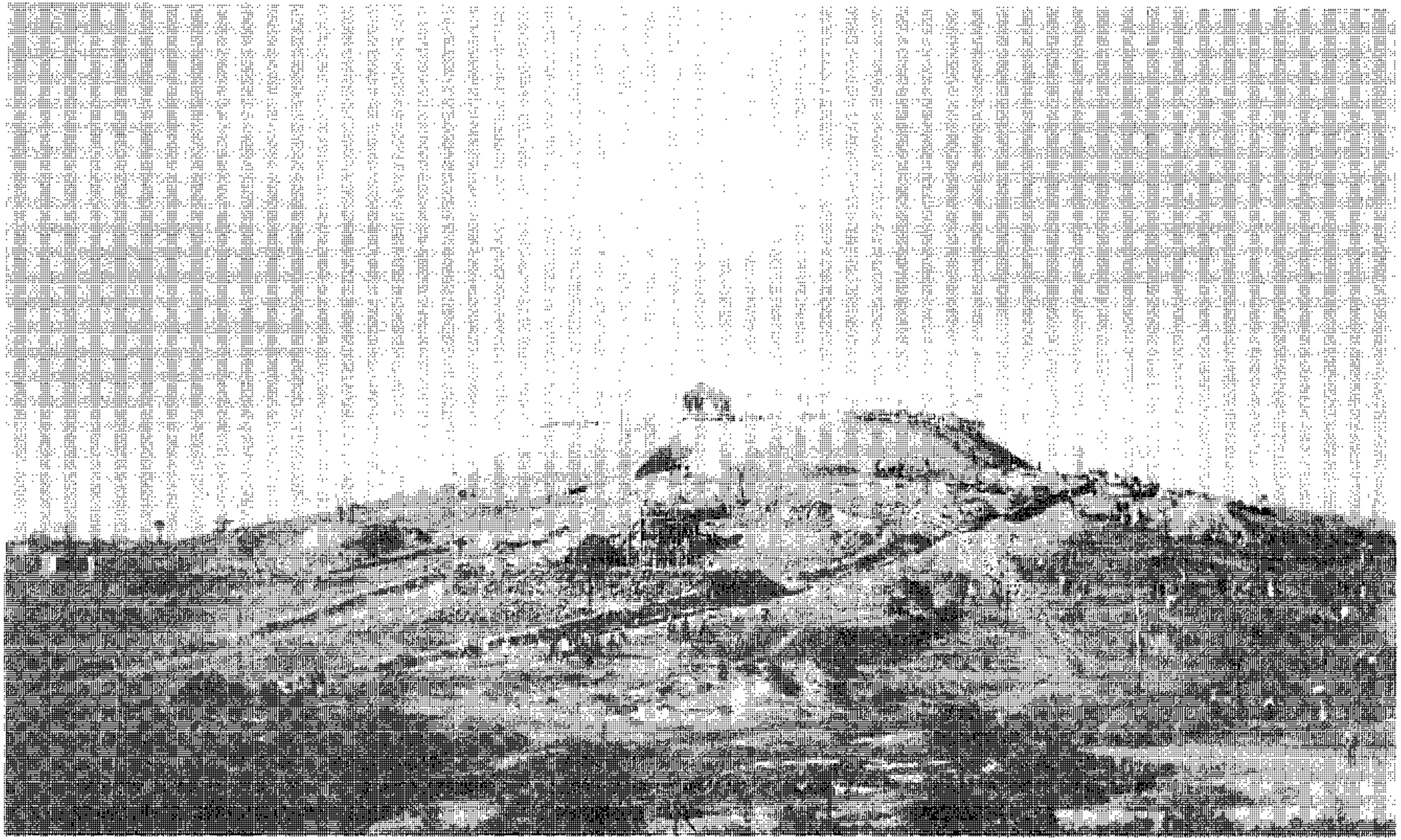
Bulla Bulling Reservoir: Method of construction



Main Street in a typical Goldfields Town



The water arrived at Cunderdin in April 1902



Opening day at Mt Charlotte Reservoir, Kalgoorlie on Saturday 24 January 1903

APPENDICES

1 REPORT TO THE WEST AUSTRALIAN PARLIAMENT, 1896 BY THE ENGINEER IN CHIEF, C. Y. O'CONNOR

2 REPORTS OF THE COMMISSION - 3rd AUG AND 31st DEC 1897

3 COMPLETE TEXT OF C. S. R. PALMER'S PAPER TO THE INSTITUTION OF CIVIL ENGINEERS, 1905

4. BOOKLET: FACSIMILE EDITION OF 'NORTH EASTERN GOLDFIELDS, FROM KOOKYNIE TO LAVERTON' - 1903

5 COMPLETED NOMINATION FORM AND CORRESPONDENCE

Appendix I

WESTERN AUSTRALIA

COOLGARDIE GOLDFIELDS

R E P O R T

ON

P R O P O S E D   W A T E R   S U P P L Y

(BY PUMPING)

FROM RESERVOIRS IN THE

GREENMOUNT RANGES,

- - - - - - - - - - - -

BY

C.Y. O'CONNOR, M. INST. C.E.,

Engineer-in-Chief.

- - - - - - - -

Presented to both Houses of Parliament by His Excellency's Command.

- - - - - -

COOLGARDIE GOLDFIELDS

PROPOSED WATER SUPPLY (BY PUMPING) FROM RESERVOIRS IN THE GREENMOUNT RANGES

Engineer-in-Chief's Office,
PERTH, W.A.
17th July, 1896.

The Hon. the Director of Public Works:-

Sir,

1. As regards the proposal to supply five million gallons of water to the Coolgardie Goldfields by pumping from a reservoir, or reservoirs, to be constructed in the Greenmount Ranges, concerning which you have desired me to send you a report, I would ask, in the first place, to be permitted to say (as there appears to be a tendency to misconception on the subject) that this proposal should not be regarded as an undertaking which I am urging upon the Government for adoption, as it would manifestly be quite improper for me, as a servant of the Government, to urge upon the Government, or upon the public, any new undertaking, unless it were the case that such undertaking were necessary for the maintenance of some work already in existence or provided for, and for which I am responsible - which cannot be held to be the case in this instance.

2. I need scarcely say, therefore, that I never urged, nor do I now propose to urge upon the Government or the country, the undertaking of this work, but, while it would evidently be quite improper for me to do that, it is equally evident that if I am called upon by the Government to give an opinion, as to the best way of attaining a certain object, it is clearly my duty to give such opinion to the best of my ability.

3. When the proposal to supply five million gallons of water, by pumping from reservoirs in the Greenmount Ranges, is referred to, as it frequently has been referred to, as being <u>my</u> proposal, it can therefore only be properly held to be so, in so far as being, in my opinion, the best means of attaining the object in view, and not in any way as being a fancy project of mine (as some persons have described it), which I am desirous of thrusting upon the Government and the country.

PROSPECTS OF RESERVOIRS IN THE GREENMOUNT RANGES AS COMPARED WITH RESERVOIRS IN THE COOLGARDIE DISTRICT

4. Such being, as I understand it, the state of the case in this instance, viz., that I am called upon to give an opinion as to the best way of attaining a large and permanent supply of water for the Coolgardie Goldfields, I have no hesitation whatever in saying that such supply can be attained in the cheapest and most certain manner by pumping from reservoirs to be constructed in the Greenmount Ranges.

5. A few of the many reasons which have led me to this conclusion, are as follows:-

   (a) The rainfall, as recorded in Perth, during the last 10 years, shows maximum 40.73 in. (in 1890), minimum 23.72 in. (in 1894), and average 33.63 in. per annum.

   (b) As compared with this, the rainfall in the Coolgardie District, during the year 1895 (which is the only complete year of which we have record, and which is believed to have been an exceptionally wet year), was only 6.79 in., and it cannot, I think, therefore, safely be assumed that the average rainfall there would exceed, say, about 5 in. per annum. In confirmation of this, too, we have the fact that the average annual rainfall at Southern Cross during the last two years has been only 5.26 in.

   (c) The evaporation, as recorded at Perth during the last 10 years, has averaged 54.32 ins. per annum.

   (d) As to what has been the average annual evaporation at Coolgardie, for a series of years, we have no records to show, but it must manifestly be very much greater than at Perth, as the maximum temperature in the sun is much greater, and the number of wet and damp days to the year much fewer.

   (e) Although we have no actual records of rainfall and evaporation at the site of the proposed reservoirs in the Government *(sic)* Ranges, it can safely be assumed that the rainfall will probably be more, and the evaporation less, than at Perth, as such is usually found to be the case on the sides of ranges facing the sea, as compared with the adjoining flats.

   (f) The character of the country in the Greenmount ranges is much more favourable, both as to gathering areas, and ground capable of holding water, and construction of weirs, than any place which we know of in the vicinity of Coolgardie.

(g) Some of the gathering areas in the Greenmount Ranges are, in fact, exceptionally favourable, the inclination of the stream beds being so gentle that a weir of moderate height would back the water for several miles: while, at the same time, the sides of the hills, forming the gathering grounds, are so steep, as to give promise of a large percentage of the water which falls upon them reaching the reservoirs. There are also sites at which weirs can be constructed on bed rock throughout.

(h) As compared with this, there are no known sites for reservoirs in the Coolgardie district having anything like the advantages of the sites in the Greenmount Ranges, either as regards gathering capacity, or holding capacity, or facility for construction of weirs: and the sites known of are, in fact, few and small, and generally unsatisfactory.

(i) Thus, for instance, from our experience in the construction of reservoirs on the goldfields up to date, although we have selected the very best sites which were available: and although the reservoirs, in most cases, have only a capacity of about one million gallons, there are many of them which have never been filled, and some of them into which hardly any water has come at all: and some of them leak very badly (in consequence of the kaolin formation, which generally prevails in the district, having fissures in it, through which the water escapes): and they have, moreover, been very costly, by reason of their being on the goldfields, as well as by reason of the cost of getting plant and materials to them.

(j) In this connection, it is also desirable to point out that, as compared with a million gallons or so, which has been about the average capacity of the reservoirs so far constructed in the Coolgardie District, the capacity of the reservoir or reservoirs required to supply five million gallons of water per diem, even if constructed at Greenmount, should be at the least 2,000 million gallons (in order to be equivalent to one year's supply): while, if constructed in the vicinity of Coolgardie, the capacity would have (other things being equal, and in view of the respective rainfalls, and evaporation, and soakage) to be probably many times greater than that, and this, I may say, is a very important aspect of the question, as it thus becomes evident that the construction of reservoirs at Coolgardie would not alone be much more costly, at per million gallons (as already stated) than reservoirs in the Greenmount Ranges, but also that they would have to be very much larger, in order to produce a given result.

(k) Another important element in the matter is that the depth of such reservoir or reservoirs as could conveniently be constructed in the vicinity of Coolgardie, so far as is at present known, would have to be very much less than the depth of reservoirs which could quite conveniently be constructed in many of the gorges of the Greenmount Ranges, and it is scarcely necessary to say that the percentage of loss in a shallow reservoir is very much greater than in a deep one.

(l) That is to say, in fact, assuming the evaporation to be, say, seven feet per annum, the loss in a reservoir 20 feet deep would be 30 per cent., whereas in a reservoir 70 feet deep it would be only 10 per cent.

(m) To sum up, therefore, as regards the question of the most favourable site for reservoirs (in the event of reservoirs being adopted as the source of supply), there cannot, I think, be the slightest doubt that the results from reservoirs in the Greenmount Ranges would be vastly more satisfactory, in every way, than any results which could be reasonably expected from reservoirs in the vicinity of Coolgardie, and, in this connection, there is one most grave and important consideration, which should never be lost sight of, viz., that whereas a continuous suppply of large magnitude from reservoirs in the Greenmount Ranges can be looked upon as a matter of absolute certainty, for an easily ascertainable cost, the results to be anticipated from reservoirs in the vicinity of Coolgardie, and the cost of such reservoirs, would be absolutely impossible of ascertainment from any data which we have got now, or could hope to get within any reasonable time. I would submit, therefore, that the undertaking, at the present time, of the construction of reservoirs in the Coolgardie District, to supply anything approaching the quantity of water herein in question, could not be regarded as otherwise than a wild leap in the dark.

POSSIBLE SOURCES OF SUPPLY OTHER THAN RESERVOIRS

Artesian Springs

6. Coming now to the question of various possible means of supplying water for the requirements of the Coolgardie Goldfields, which have been suggested, other than by surface reservoirs, there is the much-talked of possibility of attaining artesian water: concerning which, however, everyone who has studied it, and who can be looked upon as in any way an authority on the subject, has given his opinion that it is in the very last degree improbable. I think, therefore, that as regards artesian water, in the ordinary acceptation of the term - that is to say, water under high pressure, which will cause it to rise to the surface, or above the surface (and which, consequently, has come from mountain ranges of considerable height and not too far distant) can safely be left out of the question.

7. Before leaving this phase of the question, I would wish to say, that while it has many times and by many people been broadly asserted that geologists have been more often wrong than right in their predictions as to the probability, or otherwise, of obtaining artesian water, and that, especially in the case of the copious and famous artesian supply in Queensland, they predicted distinctly against the probability of it, I have never, myself, been able to find any important case which bears out these assertions: and, as regards the case of the Queensland artesian basin especially, I am altogether disinclined to believe the assertion, as it seems to me, from geological sections which I have seen of the country there, that they point in a most distinct manner to the very great probability of artesian water being found, and also to the probability of its being found under high pressure. I cannot, therefore, believe that even any ordinary layman, having the most rudimentary knowledge of the conditions which govern an artesian supply, could have had any doubt as to artesian water being likely to be found under such conditions as the geological surveys show to exist in the Queensland artesian area, and, if this would apply to a layman, it would apply still more so to a geologist.

8. Taking, again, one more instance, viz., the case of the artesian water which has been struck in the vicinity of Guildford, I would wish to take this opportunity of mentioning a fact, which I do not believe is very generally known, as regards that supply, namely, that the undertaking of the bore there by the Government was chiefly due to the light thrown upon the conditions existing there by Mr. Woodward, the Government Geologist of Western Australia, in the year 1891, and to his distinct opinion that artesian water, under considerable pressure, was present there. In this case, too, the geological conditions, upon which Mr. Woodward based his opinion, were distinctly less obviously favourable than those which prevail in the artesian district of Queensland.

<u>UNDERGROUND Stores of Water, not under Pressure</u>

9. While believing that artesian water, in the true sense of the term, will never be obtained in the Coolgardie District, there are, however, several experts who believe that underground stores of water will be found there: most of them probably salt, but some of them possibly fresh, or, at any rate, drinkable - but which will not probably rise to any considerable height, if at all, above the level at which they are struck.

10. In relation to these possible underground stores of water, however, we have to face the facts:-

(a) That they will only probably be found (in large quantities) at very great depths.

(b) That in order to utilise them, they would have to be pumped from these very great depths.

(c) That, if they are salt, they would have to be condensed before being of any use for human or animal consumption.

11. Taking, first, in reference to item (a) above, the question of the bores necessary to reach such waters at great depth, it is not, I think, generally realised what a length of time it takes to put down such bores: and I therefore enclose herewith (vide Appendix A) an extract from a newspaper showing the time which it took to put down a bore of this description in Queensland (which, by the way, never reached water at all), the rate of progress being stated to have been unusually rapid: while the time taken to bore 3,000 feet is stated to have been two years.

12. It is evident, therefore, that even the first preliminary part of the business, viz., the finding of the water at depths of 3,000 feet or thereabouts, would take a long time, especially if several places had to be tried before such water was struck.

13. Then again, as regards item (b), it is scarcely necessary to say, that any pumping which could be done from a depth of anything like 3,000 feet, through an ordinary borehole (if practicable at all) would be the merest trickle.

14. If, however, it is suggested that having found water, we should then put down a large shaft, through which to do the pumping, this shaft would take probably several years to complete.

15. Besides this, too, if one is to seriously contemplate the undertaking of pumping from the bottom of a shaft 3,000 feet deep, it should be borne in mind that the total head to be overcome, between a reservoir on the Greenmount Ranges and the top of Mount Burges (including friction head) on the basis of the pumping scheme at present under consideration is only 2,505 feet: and I have no doubt whatever, in my own mind, that the cost of pumping five million gallons daily, against this 2,505 feet, in the open, would be much less than pumping a similar quantity from the bottom of a shaft 3,000 feet deep.

16. Besides this, too, the amount which such shaft might cost would be utterly impossible to estimate, from any data which we have got at present, but it would, most assuredly, be very large indeed.

17. Over and above all this, also, there is the still more serious consideration that it would be utterly impossible to ascertain as to what quantity of water there might be in such underground reservoir, and consequently as to how long it would last, and, it might consequently be found, after an enormous expense had been gone to, that it would run dry in a few weeks or months.

18. Such, in fact, has been our experience in a great number of cases where we have found underground reservoirs of water, at depths of from 100 to 200 feet, and from which we have pumped steadily as much as from 2,000 to 3,000 gallons a day, for as long as a year or two, but which eventually suddenly gave out (their existence having probably been due to long ages of accumulation), and have never since returned to the condition in which we found them, and some of them have, in fact, remained apparently quite dry.

19. To adventure hundreds of thousands of pounds, with the possibility of such a result as that, would, I think, be altogether unwarrantable.

20. Coming now to Item (c) above, it is scarcely necessary to say that if the cost of supplying water from very deep bores, or shafts, of this description, would probably compare unfavourably (as I believe it would) with the cost of supplying water from reservoirs in the Greenmount Ranges, the comparison would be still more unfavourable, to the bores and shafts alternative, if the water obtained therefrom were salt: as it can safely be stated that the cost of condensing such salt water (and it is very salt indeed) as prevails in the Coolgardie District, would never be less than from 6 to 12 per thousand gallons, whereas water could be delivered from the Greenmount Ranges at from 5s. to 6s. per thousand gallons.

21. With further reference to the idea of procuring a sufficient water supply for the Coolgardie Goldfields by the aid of bores and shafts, I should mention that the mere raising of water in this way to the surface would be only one item in the cost: the lifting of it to a further height, in order that it might be carried by gravitation over a radius of 50 miles or so, or (in the absence of any such convenient height in the vicinity) the pumping of it directly to the surrounding places, being another very considerable item in the cost.

PRESENT PROPOSAL

How it was arrived at.

22. Having thus discoursed upon the various alternative schemes for supplying a large quantity of water to the Coolgardie Goldfield, I now come to the proposal immediately under consideration, viz., the pumping scheme from reservoirs in the Greenmount Ranges.

23. As regards this scheme, I should first mention that, at the primary stages of its inception, there were a number of calculations gone into (and published) with the view of ascertaining the probable cost of three several quantities per diem, viz., one million gallons, five million gallons, and ten million gallons, respectively.

24. The result of these calculations went to show (as for steel pipes) that, for one million gallons daily, the cost would be from, say £700,000 to £1,000,000 (depending upon the size of the pipe), and with cost of delivery varying from 5s. 6d. to 8s. 6d. per 1,000 gallons: while, for five million gallons daily, the cost varied from, say £2,200,000 to £2,700,000 (depending similarly upon the size of the pipe) with cost of delivery varying from 3s. 5d. to 6s. 7d. per 1,000 gallons: and that, for ten million gallons daily, the cost varied from, say, £3,500,000 to £4,600,000 (depending similarly on the size of the pipe), with cost of delivery varying from 3s. to 5s. per 1,000 gallons.

25. From these figures it was apparent that the cost of delivery per 1,000 gallons was not altogether dependent upon the total capital cost, but was also dependent upon the cost of pumping, which usually varied in an inverse ratio to the size of the pipe, and consequently to the total capital cost.

26. These published figures, however, related only to the cost of constructing and working a water supply to the top of Mount Burges, and contained no provision for distributing mains therefrom, which latter are included in the proposal now in question.

27. In addition to the calculations which were printed and published as above-mentioned, there were also a large number of further calculations gone into, the object being to ascertain with certainty as to what size of pipe, and consequent power of pumping engines, would give the cheapest result, in view of the relative capital cost and interest thereon, etc., and the outcome of all these calculations is the table hereto attached (Appendix B), wherein the proposal is to construct works and machinery capable of supplying five million gallons daily, together with 100 miles of distributing mains from Mount Burges, at a total estimated cost of £2,500,000, the working expenses (including sinking fund and maintenance, etc.) being estimated at £320,000 per annum, and the probable cost of delivering the water, as deduced therefrom, being 3s. 6d. per 1,000 gallons. In this connection it should be mentioned that the price of steel has gone up very considerably since the original estimates were made, and the estimates herewith have been based on the present price, which will not probably be much, if at all, increased within the next few years, as it is considerably higher than it has been for the last few years. The thickness of pipes provided for has also been increased since the original estimates were made, as it was thought possible that the original thickness might not be concurred in by English Engineers, although it was believed to be quite sufficient, and was also quite in accordance with the practice in America, where such pipes have been a speciality for many years past.

Why the Proposal is for 5,000,000 gallons per diem.

28. I now come to a very important phase of the question, namely, as to why the proposal is for 5,000,000 gallons daily, rather than for any lesser or larger quantity: and while adhering to what I have said in the beginning of this memorandum, to the effect that it is not for me to urge upon the Government the desirability of launching out in any new undertaking, and that I have no wish to do so, it is only right that I should say that, as regards the scope of the undertaking (presuming that it is to be undertaken at all), I have distinctly advised the Government for technical and other reasons that it is desirable, if any pumping scheme for supplying water to Coolgardie from the Greenmount Ranges is undertaken, that it should be for not less than 5,000,000 gallons.

29. Taking the "other reasons" first, these, amongst others, are to the effect:-

(a) That whereas a supply of one million gallons daily, including distribution mains, would cost about £1,000,000, a supply of five million gallons daily, also including distributing mains, would only cost £2,500,000: that is to say, that while the quantity would be five times as great, the cost would be only two and a half times as great: and, moreover, in consequence of the proportionately greater cost of pumping through a smaller main, the rate for which water could be delivered would be considerably greater for the smaller scheme than for the larger one, viz., as much as 5s. 6d. per thousand gallons for the one million gallons per diem scheme, as compared with 3s. 6d. per thousand gallons for the five million gallons per diem scheme.

(b) In further pursuance of the "other reasons" basis, there was the fact that it seemed to me that it would be rather ridiculous to avowedly undertake a scheme for the supply of water to Coolgardie, if it were probable that the water would be all used, for various purposes, before it got to Coolgardie at all: and I think that that would be so, or very nearly so, if only one million gallons per diem were provided for.

(c) Furthermore, on the same basis, it seemed doubtful if the pipe-laying, etc., the whole way to Coolgardie, would be justifiable, if there were no water to go through it beyond Southern Cross or thereabouts.

30. Coming now to the "technical reasons", they are briefly to the effect that if a one million gallons per diem scheme had to be augmented, as I believe it would have to be in a very short time, the number and situation of the pumping stations would be so very different from what would be required for a five million gallons per diem scheme (which might have to follow), that it would possibly involve there being as many as twenty or more pumping stations for the two schemes, whereas eight or ten would probably be sufficient for the five million gallons per diem scheme, and the same number and situation would suit for any duplication or triplication thereof which might become necessary in the future.

31. For further details on this subject, vide Appendix C hereunder.

As to the proposed Scheme being practicable

32. As regards the practicability of this scheme, there cannot, I think, be any reasonable doubt, as it has already been declared to be quite practicable by many competent engineers, even while some of them deprecated it from other points of view.

33. To say, in fact, that it is not practicable, must surely involve a misconception of the question, as there are few people who do not know of an equal quantity of water having been jumped through a lesser height, and for a shorter length, than as provided for in this scheme, and, when it is realised that this scheme, although probably of larger magnitude than others which are within the knowledge of most people, is simply a repetition, several times over, of schemes which <u>are</u> within the knowledge of most people, it is difficult to realise how anyone can consider it to be impracticable.

34. Thus, for instance, if it were proposed to pump, say, 5,000,000 gallons daily, to a height of, say, 300 feet, I cannot imagine that anyone would consider that to be impracticable: and, if it is not impracticable to do that once, it cannot surely be impracticable to do it eight times in succession.

35. As to what is practicable again, it may not be out of place to instance a fact which is known to many people in this Colony, namely, that the dredge "Premier" has frequently filled her hoppers with 600 tons of sand in 20 minutes: and, as it has been found by experience, that the quantity of sand which can thus be pumped, is about 1-5th of the accompanying water, it follows from this that the pumps must be capable of lifting at least 3,000 tons of water in 20 minutes, which is equivalent to 9,000 tons of water in an hour, or 216,000 tons of water in 24 hours, and, as a ton of water is equal to 224 gallons, this would mean 48,000,000 gallons (or, say, in round figures 50,000,000 gallons) in 24 hours.

36. The height to which the water is raised by this pump is only about 10 feet, but, on the other hand, 50,000,000 gallons of water is 10 times as much as 5,000,000 gallons of water, and consequently the same power would lift 5,000,000 gallons of water per diem through a height of 100 feet: and, in this case, there is only one pump, whereas it is proposed to have several pumps at each of the 8 or 10 pumping stations, so that there can manifestly be no practical difficulty (by the aid of several pumps at each of the pumping stations) in raising 5,000,000 gallons per diem, through the height of 300 feet or so, which will intervene between each pumping station and the next one.

<u>As to the probable capital cost</u>

37. As regards the estimated capital cost, I believe that the works can be carried out for the amount stated.

38. As regards the pumping engines, which constitute an important item in the Estimate, the amount set down for them is based upon information specially obtained from England for the purpose. (Vide Appendix D hereunder).

39. As regards a still more important item, namely, the pipes (weighing about 90,000 tons) the estimate is supported by prices at which manufacturers have offered to deliver the piping required.

40. As regards the cost of the reservoirs, which is another very important item in the estimate, there is ample evidence that they can be constructed for the amount set down. (Vide, inter alia, Mr. Hodgson's memorandum to me, dated 15th instant, hereunder, Appendix E).

41. As regards the other items in the estimate, which are for works of an ordinary and everyday character, there is no reason to doubt that the ordinary prices, at which they have been valued, will be found to be sufficient.

<u>As to the probable Working Expenses</u>

42. As regards the estimated working expenses per annum, which include interest and sinking fund, as well as maintenance, and cost of pumping, and general administration.

(a) The amount set down for annual interest and sinking fund is sufficient to pay interest on capital, and also to pay off the said capital in a period of about 20 years.

(b) The amount set down for maintenance is sufficient to keep the whole of the works and machinery in good going order.

(c) As regards the probable cost of pumping, this has been deduced from various well recognised authorities on the subject, notably, amongst others, "Unwin on the Development and Transmission of Power", with due allowance, of course, for the local price of coal, and labour, etc.

(d) As regards the general administration, it simply means (in view of there being ample provision for maintenance) the collection of the revenue, and the keeping of the accounts, and it is believed that 5 per cent. on the revenue should be ample for that purpose.

<u>As to the Price at which the water can be delivered</u>

43. The estimated price at which the water can be delivered, viz., 3s. 6d. per thousand gallons, is simply an arithmetical resultant from the total estimated working expenses per annum, on the basis that five million gallons (on the average) will be sold daily, during 365 day in each year: but, as regards the "on the average" element in the matter, it is only right to say that this result would not accrue if the five million gallons per diem failed to be sold for several days running, as the estimate only provides for a storage reservoir at Mount Burges capable of holding two or three days' supply.

44. It is, however, proposed to keep all the reservoirs along the pipe line continuously full, by aid of the pumping main: and this would, to some extent, restore the balance, if the quantity available failed to be sold for more than two or three days at a stretch: as the working railways, for instance, could then use the water out of the reservoirs along the line, instead of taking it from the pumping main.

<u>Benefit to Working Railways</u>

45. As regards the working railways element in the matter, it is shown, in Appendix C hereinbefore referred to, that the requirements would be about 200,000 gallons per diem, for eight months in the year, and that the saving which would be attained by obtaining this supply by the pumping scheme, instead of, as is done at present, by hauling it in running tanks, would be about £30,000 per annum.

<u>Water can be delivered in the Coolgardie District by this Scheme cheaper than by any other method that we know of</u>

46. Coming now to the question as to how the cost of water delivered by this pumping scheme to the Coolgardie District would compare with the cost of water delivered by any other method, I find, as is shown in Appendix F hereunder, that the cheapest of all the water supplies hitherto existing in the Coolgardie District, viz., the supply from reservoirs constructed by the Government, cost the country (exclusive of the cost of maintenance of the reservoirs themselves), concerning which I have at the moment no actual data) at least 8s. 6d. per thousand gallons: and, if the maintenance of the reservoirs were taken into consideration, it would, I have no doubt, bring the cost up to fully 10s. per thousand gallons.

47. It is manifest, therefore, that the pumping scheme would attain a very large reduction on even the cheapest rate at which water has hitherto been obtainable (and there was, really, in all, a very insignificant supply obtained at that rate), and, that being so, it is needless to say that the pumped water would be enormously cheaper than water obtained from any of the other sources of supply of which we have any present knowledge.

48. As compared with condensed water, in fact, as already alluded to, the cost of this pumped water would be only about half as many shillings per 1,000 gallons as the condensed water costs in pounds per 1,000 gallons, and often even less than that.

49. Looking at the matter from the point of view as affecting the whole of the community on the Coolgardie goldfields in the future, the difference in the cost at which they could obtain the quantity of water absolutely necessary for human consumption, by this pumping proposal, as compared with the cost at which they obtain it now, is simply marvellous, the figures being about as follows:-

50. That is to say, I have seen it stated recently that there are as many as 40,000 people in the Coolgardie District, and although I scarcely think that that can be so, it is quite probable that that number of people may be congregated there by the end of the three years which this pumping scheme would take to complete.

51. If we assume that each of these 40,000 people has to pay even as little as 6d. a day for water, which would be only allowing them from two to three gallons per diem, as prevails under existing conditions, this would amount, for the 365 days in the year, to £9 per annum for each person, and the total, for 40,000 persons, at that rate, would be £360,000 per annum, whereas the same quantity of water could be attained by proposed pumping scheme for less than £10,000 per annum. It is evident, therefore, that if

pumping from the Greenmount Ranges is adopted, as compared with any local source of supply that we know of, there would be relief to these 40,000 people to the extent of £350,000 per annum, whereas the whole annual working expenses of the pumping scheme would be only £320,000 per annum.

52. Besides this too, there is the fact that after all these people had been supplied by the pumping scheme, with the same quantity of water which they got before, there would still be about 1,750 million gallons of water per annum available for other purposes. That is to say, the total quantity, equivalent to 5,000,000 gallons per day, for 365 days in the year, being about 1,800 million gallons per annum, and the quantity which would be consumed by 40,000 people, under the existing conditions, viz., at the rate of, say, 3 gallons per head per diem, being less than 50 million gallons per annum, there would, as before stated, be 1,750 million gallons per annum, out of the total of 1,800 million gallons of water if sold, as it is assumed that it will be, for mining and other purposes, at the rate of 3s. 6d. per thousand gallons, the relief to the 40,000 people above mentioned to the enormous extent of £350,000 per annum, would be attained without any cost to the country whatever.

<u>Time which the work will take to complete</u>

53. There is, I think, only one more point which I need touch upon, viz., as to the estimate that the work can be completed in three years, concerning which I have to state as follows:-

(a) We have been assured by steel pipe manufacturers that the whole of the pipes required could be made in two years.

(b) If the delivery of these pipes were commenced, within even six months of the date of the work being authorised, and completed in 30 months from same, they could, I have no doubt, be all laid within the three years.

(c) If, again, the excavation of the pipe trench were started almost immediately after the work was authorised (as it could be) there is no reason, that I know of, why it could not be kept well ahead of the pipe-laying, and consequently also completed within the three years.

(d) As regards the pumping engines and sheds for same, there is no reason at all, that I know of, why they could not be procured and erected and constructed, respectively, within three years.

(e) As regards the reservoir, or reservoirs, they would, no doubt, have to be designed with great promptitude, and put in hand as soon as possible, in order to be completed within three years, but there is no reason that I know of why they should not be completed within that time.

Advantage of traversing three or four hundred miles of dry country

54. In addition to the various reasons, set forth above, as to why the proposal to pump water from reservoirs in the Greenmount Ranges is preferable to any other means of supplying water to the Coolgardie Goldfields, which we are at present aware of, there is the very important consideration that the water supply would thus traverse three or four hundred miles of, comparatively speaking, waterless country, comprising the auriferous areas of Southern Cross, and that it would, therefore, have numerous, and probably at present altogether unexpected advantages, over any water supply which was merely local in the Coolgardie District.

Further Appendices, not previously mentioned

55. Attached hereto, in addition to the appendices already referred to, there will also be found an extract from a recent report by the Engineer in Charge of Water Supply on the Goldfields (Mr. Hector), containing some remarks on the subject herein referred to (Appendix G)*, and also a drawing (P.W.D. W.A. 4,053)* showing the route of the railway along which the pumping main is proposed to be constructed, and also a profile of the ground along said route.

Desirability of asking for advice from European Specialists, as regards location of Pumping Stations, etc.

56. In conclusion (and in reference to observations by members of the Legislature on the subject), I would wish to mention that it has always been my intention, in the event of this pumping scheme being adopted, to recommend the Government to arrange for a consultation of high-class specialists in England, more particularly as regards the height and distance which it would be most desirable to adopt between the several pumping stations, and consequently the location

* Publisher's Note - Appendices not found.

of the said pumping stations, and the consequent number and power of pumps, which it would be most desirable to adopt for each such station, and, in evidence of this, I attach hereto a letter which I addressed to our Consulting Engineer in England, Mr. Carruthers, dated 3rd March last (Appendix II)*, and also extracts from his reply thereto (Appendix I)*.

I have the honour to be,

Sir,

Your obedient Servant,

C.Y. O'CONNOR

Engineer-in-Chief.

---

* Publisher's Note - Appendices not found.

APPENDIX A

Extract from "The Queenslander", dated April 25, 1896

- - - - - - - - - - - -

THE DIAMOND DRILL ON CHARTERS TOWERS

The bore was commenced in January, 1894 (says "The Northern Miner"), and put down to a depth of 2,135 feet, entirely at the expense of the Golden Gate Gold Mining Company, and, from 2,135 to 3,006 feet, the Government granted a subsidy of 50 per cent. of cost, and the No. 7 North-East Queen Company contributed 25 per cent. The cost per foot has been a little more than £1. The boring operations, under the management of Mr. J. Cole, have been remarkably successful, an average of about 60 feet a fortnight being maintained (one shift). This established a record far ahead of any similar work done in Queensland, and it is believed to be also a record bore for the world in granite. Many cores of great length, from over 16 feet, according to the solid character of strata, have been obtained sometimes without a flaw or vein of any kind, and as smooth as a gun barrel. It is not improbable that this bore may be continued to a still greater depth at some future time, as the last cores raised were distinctly favourable and similar in character to the overlying strata of some of the reef formations. Mr. Cole believes the machinery is equal (with a little alteration to the lifting gear) to 4,000 feet. The weight of rods in use to present depth is about 15 tons. The whole of the work has been almost entirely free from accidents. Two diamonds (carbons) about two carats each, were left below, owing to the defective metal in the bit, at 1,575 feet and 2,855 feet, but on each occasion Mr. Cole succeeded in picking them up in a few hours by the aid of a tool designed by himself. An opinion seems to have got abroad that, as far as reefs and formations are concerned, the bore had been entirely unsuccessful, but the "synopsis of the strata penetrated" is a reasonable proof that, though but little quartz has been pierced, yet the formations undoubtedly exists here at greater depths than has yet been attained by any of our mines.

Concerning the above, the "Gympie Times" says:- From a private source we learn that it is now suggested on the Towers to have a bore put down about 2,000 feet, near the junction of the Queen Cross Reef, the Victoria and Queen, the Victoria and Caledonia block, and the Band of Hope, and that the Directors of the Victoria and Queen, and Queen Cross Companies favour the idea, and the Directors of the other two Companies intend to consult the shareholders. We congratulate Mr. Cole on his great achievement with the bore.

- - - - - - - - - - - -

Continued

THE HON. THE DIRECTOR OF PUBLIC WORKS. For your information.

The results achieved in this case, namely 30 feet per week, are stated to be exceptionally good for boring in hard rock, and, if that is so, the boring at Coolgardie could not be expected to go any faster, and it would thus take 100 weeks to bore the 3,000 feet contemplated.

In view of this, it seems to me that the postponing of other projects for the supply of water to Coolgardie until the result of boring to a depth of 3,000 feet is known, that is to say, the postponing of them for at least 2 years from now, would probably not be practicable, even if it were considered to be wise, and personally I do not think it would be wise.

You will also, no doubt, notice that although the boring hereinabove described (regarded as boring work simply) is considered to be very satisfactory, there is nevertheless the fact that they got no water.

C.Y. O'CONNOR

15/5/96

- - - - - - - - - - - -

APPENDIX B

COOLGARDIE GOLDFIELDS

PROPOSED WATER SUPPLY FROM RESERVOIR ON HELENA RIVER

Estimated cost of supplying 5,000,000 gallons daily by pumping through steel pipes.

Description	Unit of Measure	Amount
BASIS OF ESTIMATE		
Length of pipe, storage reservoir to Coolgardie	Miles	330
Velocity of water per second.	Feet	2
Diameter of pipe required.	Inches	30
Net height which water has to be pumped.	Feet	1,350
Head required to overcome friction per mile.	do.	3.5
Total head required to overcome friction.	do.	1,155
Grand total head which pumps have to overcome (including friction head).	do.	2,505
Weight of water which has to be raised per day of 24 hours (including water for engines, evaporation on Fields, and other losses).	Tons	23,000
Work required to be done, per day of 24 hours.	1,000 foot tons	57,615
Horse-power required - effective.	No. of h.p.	2,716
Horse-power required - actual (being effective horse-power plus 33 per cent).	do.	3,612

Description	Unit of Measure	Amount
CAPITAL COST		
Pumping engines and sheds for same, at £55 per horse-power.	Pounds Stirling	200,000
Main pipes (including valves &c.) at Fremantle, 90,000 tons.	do.	1,470,000
Main Pipes, Carriage from Fremantle.	do	140,000
do. Laying and Jointing (including excavation and filling in of pipe trench, etc.)	do.	220,000
Reservoirs. ...	do.	300,000
Distributing mains (including trenching, laying, and jointing, &c.) 100 miles, averaging, say 12 in. diameter.	do.	170,000
Total capital cost.	do.	2,500,000
WORKING EXPENSES PER ANNUM		
Interest and sinking fund on total capital cost at, say, 6 per cent.	do.	150,000
Maintenance.	do.	45,000
Cost of pumping 5,000,000 gallons daily for 365 days at 1 1/4d. per 1000 foot tons, say.	do.	109,000
General administration, 5 per cent. on revenue.	do.	16,000
Total working expenses.	do.	320,000
PRICE AT WHICH THE WATER CAN BE DELIVERED.		
Cost per 1,000 gallons, on assumption that 5,000,000 gallons are sold daily, during 365 days in each year.		3s. 6d.

APPENDIX C

Engineer-in-Chief to the Hon. the Director of Public Works.

COOLGARDIE GOLDFIELDS WATER SUPPLY

Quantity of water per diem which should be provided for: also quantity required for Yilgarn and Coolgardie Railway.

\- - - - - -

The Hon. the Director of Public Works

1. I send herewith, for your information, Memoranda by Messrs. James Thompson and R.H. Campbell, showing the probable annual cost of water required for the Coolgardie Railway, if provided by travelling tanks, as hitherto, as bearing to some extent on the question of the desirability or otherwise of undertaking the pumping scheme for water supply for Coolgardie.

2. The figures arrived at by Mr. Thompson and by Mr. Campbell, respectively (vide in each case the fourth paragraphs of their memoranda) do not quite agree, but, in view of increasing traffic, it may, I think, fairly be assumed that in the absence of some means of supplying water, other than we have at present, it will be necessary to carry water in running tanks, as hitherto, to extent of about 200,000 gallons per diem for eight months in the year, and that the cost of doing this will exceed the cost of supplying the water by Coolgardie pumping scheme by somewhere about £30,000 per annum.

3. If the scheme to supply only one million gallons were adopted, therefore, the saving attained by being relieved from the haulage of water would just about pay the interest on estimated cost of same (about £1,000,000) and if the scheme to supply five million gallons per diem were adopted, the said saving would amount to nearly half the interest on estimated cost of same (about 2,500,000).

4. Personally, I do not think that one million gallons per diem would be anything like sufficient to provide for: and, the more I think the matter out, the more I am convinced that it would be desirable to provide for a supply of five million gallons per diem.

5. Thus, for instance, if only one million gallons per diem were provided for, the 200,000 gallons per diem estimated in the memoranda herewith to be required for railway purposes would absorb a large percentage of it: and there has also to be taken into account the requirements of the towns and villages en route, including Newcastle, Northam, York, Southern Cross, Coolgardie and Kalgoorlie: so that very little, if any, of the one million gallons would be left for mining purposes.

6. Another element in the matter, which has only recently struck me, is that if the scheme were constructed to supply five million gallons, even although five million gallons were not immediately required, there would merely be the loss of interest and sinking fund, on the difference in cost between the one scheme and the other, as the working expenses, exclusive of interest and sinking fund, need not necessarily be any greater for the larger scheme than for the smaller one, unless the larger amount of water is supplied. That is to say the largest item in the working expenses, exclusive of interest and sinking fund, is the actual cost of pumping, and if it were a fact that that were directly proportional to the quantity pumped, it would be evident that the cost of pumping one million gallons daily, through a pipe capable of carrying five million gallons daily would not be any more than the cost of pumping one million gallons daily through a pipe capable of carrying only one million gallons daily.

7. As a matter of fact, however, the cost of pumping any given quantity of water diminishes, as the size of the pipe increases, so that it is not alone the fact that the cost of pumping one million gallons of water daily, through a pipe capable of carrying five million gallons of water daily, would not be any more than the cost of pumping the same quantity through a pipe capable of carrying one million of gallons of water daily, but it is a fact that it would be very much less.

8. There is also another very important element in the question, which I have only recently studied out, namely, the location of the pumping stations in relation to the static head, and friction head, which has to be overcome: and I am inclined to think that if we were to adopt the one million gallons per diem scheme wherein the pumps would have to overcome a total head of 4,500 feet, it would probably be recommenced that there should be something like fifteen pumping stations: whereas, if we adopt the five million gallons per diem scheme, wherein the pumps have to overcome a total head of only about 2,500 feet, it would probably be sufficient to have eight or ten pumping stations: and the same number of pumping stations (namely eight or ten) would probably also be suitable for the ten million gallons per diem scheme, wherein (as it happens) the head to be overcome would also be about 2,500 feet.

9. In view, therefore, of the great probability of a supply having to be provided in the future, up to, in all probability, as much as ten million gallons per diem, it seems to me that it would be undesirable to adopt a scheme, as a first instalment of that supply, which would involve a larger number of pumping stations than would be necessary for the remainder of the supply, and which would consequently possibly involve placing the pumping stations for the two several instalments (by reason of the said instalments varying from each other so much in relative magnitude) in different places: and, if there were fifteen

pumping stations for the one million gallons per diem supply, and eight others for the five million or ten million gallons supply to follow it, there would be an altogether inconvenient and unnecessary number of pumping stations for the supply as a whole.

23rd June, 1896. C.Y. O'CONNOR.

APPENDIX "D"

COOLGARDIE WATER SUPPLY

Copies of Telegrams and Replies re Cost of Pumping Engines.

Public Works Department, W.A.,
Sewerage and Water Supply for Towns
Perth, July 14th, 1896. (Branch,

Memorandum for the Engineer-in-Chief.

The following are copies of the telegrams and answers which passed between the Premier and the Agent-General with reference to the cost of pumping engines, per horse-power, for Coolgardie Water Supply.

HORACE P. ROBERTSON

Telegram to Agent-General, 30th October, 1895.

In connection with proposed water supply for Coolgardie, by pumping from Guildford, ten million gallons every twenty-four hours, please advise as soon as possible probable weight and cost, Fremantle, of pumping engines with boilers complete, capable of developing in all 12,000 horse power, to be located at six different places, about 2,000 horse-power each place.

Answer - Telegram from Agent-General

In reference to your previous telegram, pumping engines will cost £16/4/- per indicated horse-power, weighing 1,250lbs. 12,000 horse power require 2ft. 6in. diameter main, while four 15in. diameter mains require 20,000 horse-power.

Telegram to Agent-General, 12th November, 1895.

Pumping engines - Is £16 per horse-power correct? In Mansergh's report on Melbourne drainage, Victorian Parliamentary Paper 182 of 1890, pages 47 and 50, his estimate, including sheds, is one hundred and twenty pounds per gross horse-power. Christchurch drainage engines, exclusive of sheds, cost over £50 per indicated horse power. Am aware horse power dependent on diameter of pipe, and the 12,000 horse-power is based on thirty-six inch pipe.

Answer - Telegram from Agent-General

If piping be three feet diameter we confirm. Pumping engines will cost £16 to £18 per indicated horse-power, including boiler and pipes to be used for inside sheds. The estimated cost does not include freight, foundations, and sheds.

APPENDIX E.

Engineer for Sewerage and Water Supply for Towns to Engineer-in-Chief.

Public Works Department, W.A., Sewerage and Water Supply for Towns Perth, July 15th, 1896. (Branch,

COOLGARDIE WATER SUPPLY.

Report.

Memorandum for the Engineer-in-Chief.

1. I have now the honour to submit a report and estimates of cost of your scheme for supplying Coolgardie and district with water from the Darling, or Greenmount, Ranges.

2. The amount proposed to be supplied is 5,000,000 gallons per diem.

3. I have made an exhaustive examination of the principal watersheds and streams in such parts of the Darling, or Greenmount, Ranges as are within a moderate distance of the goldfields railway line, and have had surveys made of the best reservoir sites obtainable there.

   The valleys examined are those of -

   1. Deep Creek, along the Eastern Railway Deviation;
   2. Mahogany Creek (a tributary of the above);
   3. Helena River;
   4. Talbot River;
   5. Bland's Brook, near York;
   6. Dale River;
   7. Mortlock River;
   8. Mackie River;
   9. Coraline Brook (South of Mokine);
   10. Colyaline Creek (South of Clackline);
   11. Heale's Brook;
   12. Wongamine Brook (North of Northam);
   13. Avon River (from six miles above Beverley to seventeen miles below Newcastle);

14. Toodyay Brook (North of Newcastle);

15. Boyagerring Brook (North of Newcastle);

16. Jimperding Brook (West of Newcastle); and

17. Canning River.

4. I presume you do not wish me to discuss fully, at this stage, the relative merits of these various sources of supply, but to indicate briefly and distinctly which I consider to be the safest and best.

5. This I am able to do with confidence; and I have no hesitation whatever in saying, that, at this stage, the Helena River is the source upon which our estimates should be based.

6. The respective merits of the other streams I purpose reporting on a little later on.

7. At present I cannot positively assert that none except the Helena would be suitable, but I can ask you to accept my assurance that the latter, though not the least expensive, is perfectly safe and satisfactory.

8. The estimates appended hereto, and drawn on the basis laid down by yourself, are made on the assumption that the Helena will be the source of supply. Should you, later on, decide in favour in any of the other streams, the cost of the scheme will not be increased, but rather reduced, except, perhaps, in the case of the Canning River.

9. On the Helena I have had several sites surveyed, and I can with safety recommend one situated about five miles South-West of Sawyer's Valley Railway Station. The site is almost an ideal one. The foundations at the dam site are bed rock; the valley at that point very narrow, and sides precipitous.

10. A concrete dam might be made 100ft. high, and its length on top would only be 650ft. The advantages, however, do not cease there. The river bed is comparatively flat, and the sheet of water backed up by such a dam would extend for about seven miles. The quantity of water impounded would be 4,619 million gallons, and the net amount available annually, after allowing 20ft. in depth at the dam site for silt, and seven feet from top water level for evaporation and soakage, would be 3,330 million gallons. The level of the river bed there is about 320ft. above the sea, and the distance from Coolgardie, following generally along the railway line, is about 330 miles.

11. The watershed is such that there can be no reasonable doubt about the reservoir being filled annually. The drainage area is 350,000 acres, most of it hilly and rocky; and the Helena and Darkin Rivers traverse its greatest length.

12. Assuming a rainfall of 20in. per annum over this area, the reservoir would be filled every year if only 3 per cent. of the rainfall found its way into it.

13. The quality of the water is excellent; there is practically no settlement in the catchment area, and consequently no danger of pollution.

14. Respecting the estimates of cost of the scheme, it is unnecessary to say much, as they are based upon your general instructions, and contain nothing original on my part. In the matter of the main pipe, however, I may point out that the minimum thickness of metal adopted (for the 30-inch main) is 3/16 of an inch and the maximum 5/16.

15. The formula used is that of Neville, modified (for steel pipes) to the following:-

$$t = .0007\ nd \text{ plus } .06.$$

Where t = thickness of metal required in inches.
" n = No. of atmospheres of pressure.
" d = Diameter of pipe in inches.

16. This gives a factor of safety of 5, with one-sixteenth of an inch additional, all through, for wear and oxidation. As, however, the pipes will be coated twice with Trinidad asphaltum, the second coat to be put on immediately before they are laid in place, it is expected that the oxidation will be practically nil.

THOS. C. HODGSON,
Engineer for Sewerage and Water Supply
for Towns.

APPENDIX F.

COOLGARDIE GOLDFIELDS WATER SUPPLY.

Remarks on Results obtained from 9 Reservoirs, between Southern Cross and Siberia, during the year ending 30th November, 1895, as shown on Tables "A" & "B" hereunder.

---

1. From these figures, it would appear, that the quantity of water impounded in these reservoirs, as a whole, during the twelve months ending 30th November, 1895, approximated very closely to the total capacity of the reservoirs as a whole, the quantity of water impounded being, in round figures, 10 million gallons, while the total capacity of the reservoirs was, in round figures 12 million gallons.

2. A large portion of the water impounded was, however, lost by evaporation and absorption, say, probably 4 million gallons, and that would bring the quantity actually used to, say, 6 million gallons, as compared with the total capacity of the reservoirs which is 12 million gallons.

3. The cost of the reservoirs, per thousand gallons of capacity, must therefore be multiplied by two, in order to get at the cost per thousand gallons of effective result.

4. The cost of the reservoirs having been about £2 per thousand gallons of capacity, the cost per thousand gallons of effective result, has therefore amounted to, say, £4.

5. On this basis, the interest (at, say, 5%, to allow for a sinking fund) on cost per thousand gallons would be, say, 4s.

6. Taking 6 million gallons as the quantity sold in a year, and assuming the number of caretakers to have been nine (9), at £150 per annum each, the cost of caretaking would apparently amount to about 4s. 6d. per thousand gallons.

7. The cost of supplying water from reservoirs of this description, would therefore appear to amount, in all, for interest on cost, and caretaking only (without counting maintenance, concerning which I have, at the moment, no data,) to 8s. 6d. per thousand gallons.

8. If the cost of maintenance were included, the total cost would probably be shown to be at least 10s. per thousand gallons utilized.

9. It would appear, therefore, that water can be supplied, by means of the proposed pumping scheme, at much less cost per thousand gallons, than by means of reservoirs of the description herein described, and it therefore becomes a question as to whether reservoirs of this description should continue to be constructed (unless for immediately urgent requirements) in the localities which would be supplied by the pumping scheme, to extent at present contemplated.

(Sgd). C.J. O'CONNOR
Engineer-in-Chief.

8th July, 1896.

Appendix 2

COOLGARDIE GOLDFIELDS WATER SUPPLY

REPORTS OF THE COMMISSION - 3RD AUG AND 31ST DEC 1897

12

COOLGARDIE GOLDFIELDS WATER SUPPLY

REPORTS OF COMMISSION

3RD AUGST AND 31ST DECR 1897.

COOLGARDIE GOLD FIELDS WATER SUPPLY.

Interim Report of the Commission of Engineers appointed by the Government of Western Australia.

Westminster, August 3rd, 1897.

To the Agent-General for Western Australia, 15, Victoria Street, London, S.W.

SIR,

COOLGARDIE GOLD FIELDS WATER SUPPLY.

We, the Commission appointed to enquire into this matter, having now completed a large portion of the necessary investigations, have the honour to submit the following interim Report.

The reference to us is contained in the following paragraphs of a letter of appointment, signed by you, and dated London, 11th January, 1897:—

"The enquiry is not to extend to any question of sufficiency of supply at source, but to the determination of the following:—

"Material and method of manufacture of pipes, whether welded or rivetted, and whether welding and rivetting shall be square or spiral.

"The diameter and thickness of pipes and method of protecting.

"Whether pipe line shall be continuous from pump to pump or whether it shall be broken by the insertion of reservoirs, at points as near to pumps as possible. The minimum size of such reservoirs and especially the depth.

"Whether other reservoirs should be introduced along pipe line, independently of their possible use for distribution of water along the line. If so, the best capacity, and especially their depth.

"Whether it may be advisable on parts of the line to duplicate the pipes.

"Whether it would be safe to rivet up the whole line of pipes, or whether joints to allow for contraction and expansion are necessary; the kind of joint most suitable, should they be necessary.

"Whether the pipes should be laid in a trench and covered in, or left exposed to view.

"The use of cast iron being prohibited on account of the cost and difficulty of freight, both by sea and land, the Commissioners need not take it into account.

"To fix the position of the several pumping stations and the indicated H.P. required at each.

"To advise as to the description of engine and the duty to be specified, and the reserve power at each station.

"To advise as to the fittings to be used on line."

We have perused the whole of the reports and speeches supplied to us, including the report of the Chief Engineer, Mr. C. Y. O'Connor, dated 17th July, 1896, and the additional information supplied by the Chief Engineer, dated 11th December, 1896, including a report by Mr. Thos. C. Hodgson, of Perth, Civil Engineer, dated 3rd December, 1896.

We have had the advantage in many of our deliberations of the assistance of Mr. O'Connor, have taken evidence in cases where it appeared that the knowledge of others might assist us, have visited works, the manufactures of which were of special interest in connection with the questions to be determined, and have generally informed ourselves in relation to the various matters germane to the enquiry.

As the reference to us does not extend to the sufficiency of the supply at the source, we have not taken that subject into consideration, but have confined our enquiry to the best conditions under which 5,000,000 gallons a day may be pumped from a storage reservoir to be constructed on the Helena River, in the Greenmount Ranges, about 35 miles from Fremantle, to a point near Coolgardie, about 328 miles further inland. This storage reservoir we shall call the Greenmount Resevoir.

From an examination of the plans and from information received from Mr. O'Connor it appears that, for the present at least, it would be sufficient to construct a service reservoir for Coolgardie, to be called the Coolgardie Service Reservoir, on the hill marked No. 1 on the plans, at a distance from the proposed Greenmount Reservoir of 328 miles, and at an altitude of 1,653 feet above low water level at Fremantle, and of 1,313 feet above the off-take level of the Greenmount Reservoir. Besides these two terminal reservoirs, there must be one reservoir at each pumping station, and one at about the 33rd mile from the Greenmount Reservoir. We are informed by the Chief Engineer that reservoirs can be constructed at all these sites without exceptional difficulty, but beyond this our knowledge concerning them does not extend, and we have not considered any question connected with their construction.

It may be necessary, we understand, at some future time to raise part of the supply to a reservoir to be constructed on the summit of Mount Burges, about 4½ miles from the Coolgardie Service Reservoir, and about 170 feet higher. The quantity to be so raised is not at present known, and we have not made any recommendation in regard to it. When, however, this extension of the present scheme becomes desirable, there will be no difficulty by means of an additional pumping station, in raising so much of the water from the Coolgardie Service Reservoir to the Mount Burges Reservoir as may be desired.

GENERAL STATEMENT AS TO THE PRACTICABILITY OF THE SCHEME.

It has been rightly assumed by the Government of Western Australia and their advisers that the scheme as propounded is quite practicable. Water has been successfully pumped under much greater pressures than will be necessary in this case, and has been passed through pipe aqueducts in much greater volumes. But there is an element, viz., leakage, which is brought into exceptional prominence when considered in connection with the comparatively small quantity of water—only 5,000,000 gallons a day—to be provided for in the first instance, and the great distance—328 miles—along which it has to be pumped.

We believe that, in the absence of special precaution, leakages insignificant in themselves, but occurring at a great number of points, would be a very serious matter indeed. We are satisfied, however, that with proper precautions in the design and manufacture and use of the pipes and joints, any danger of failure or serious loss from this cause may be avoided. Subject to these and to other precautions which we shall indicate, there can be no doubt that the scheme—if properly worked out in detail on the drawing board, and adequately described in binding specifications, and subject of course to due and continuous inspection of the work—may be carried out with the certainty of success.

AS TO THE DIAMETERS OF THE PIPES.

The difference of level between the Greenmount Storage Reservoir and the Coolgardie Service Reservoir being about 1,313 feet, we have assumed that in the scheme at present under consideration the whole of the water will be pumped to that height.

In addition to this height there is a frictional resistance in the main, which forms part of the head against which the pumps act.

We find that the required quantity of water can be conveyed without greater frictional resistance than is desirable by a main of 26 to 30 inches diameter. With a smaller diameter the work to be done by the pumps increases considerably. For instance, with a 24 inch main the frictional resistance is about three times as great as with a 30 inch main.

With the diameters proposed by the Commission, and provisionally set out on drawing No. 1, the frictional resistance in the mains would amount altogether to about 1,292 feet, so that the total head for the whole length of the main will be about 2,605 feet.

For such pipes as are proposed to be used the frictional resistance in feet per mile may be taken at the values in the following table:—

	Diameter of Pipe in inches.		
	26	28	30
Discharge per day in million gallons.. ...	5	5	5
Velocity in main, feet per second	2·513	2·172	1·888
Frictional resistance in feet per mile—			
Lapwelded pipes	5·103	3·538	2·497
Rivetted pipes	6·159	4·270	3·103

Using these values, and assuming such a distribution of pipes of different diameters as will satisfy the conditions of pumping power hereafter referred to, and as will enable some at least of the pipes to be nested for shipment, the total lift and friction in the main would, as above stated, be about 2,605 feet.

AS TO THE PUMPING ENGINES.

To lift 5,000,000 gallons a day to a height of 2,605 feet would require 2,743 Pump Horse Power, or allowing 5 per cent. for slight leakage from the mains, evaporation from the intermediate reservoirs, feed water and other supplies to the pumping stations, say 2881 P.H.P. This is the power which should be provided for regular work in addition to a proper reserve against accident or stoppage for overhauling the engines. In addition to this, each pumping station should have a reserve of power, sufficient to cover any exceptional leakage, if the condition of the main is properly maintained.

We are of opinion that the pumping might conveniently be done from nine pumping stations at or near the following distances from the Greenmount Reservoir, and with approximately the following lifts and Horse Powers, respectively:—

Pumping Station.	Distance from Greenmount Reservoir.	Total Lift, including friction in main.	Pump Horse power (exclusive of reserve) at each Station.
	Miles.	Feet.	
1	0	420	464
2	1	420	464
3	75·5	420	464
4	137	420	464
5	170·5	185	205
6	213	185	205
7	238	185	205
8	290	185	205
9	324	185	205
Total ...		2605	2881

It is to be observed that in the above table we have brought the pump horse power (exclusive of reserve) at each of the first four stations to the uniform figure of 464, and at each of the remaining five stations to the uniform figure of 205. We regard uniformity of the pumping machinery as of great importance.

We append to this Report a drawing, No. 1, showing the positions thus selected for the pumping stations, and the hydraulic gradients of the different sections of the main.

The question, however, of the best possible arrangement involves considerations of great complexity, and, in our final report, we may have occasion to modify the above table to a slight extent.

POSITION OF MAIN.

We are of opinion that the aqueduct should follow generally the line of railway, on account of the facility for conveying the pipes and machinery, and afterwards supplying the pumping stations with fuel and stores. In two cases, however, the aqueduct may be shortened by leaving the line of railway, and we recommend that this be done at the points marked deviations No. 1 and 2 on the plan.

Mr. O'Connor informs us that there is much salt in the soil throughout a great part of the district through which the aqueduct will pass, and we prefer on this account and for the avoidance of external earth pressure and for greater facility in the inspection of the pipes and the suppression of leakage, as well as economy in first cost, that the greater part of the main be left exposed above ground and not buried in the usual manner. This may be done in the climate of Western Australia, since there is no prolonged frost. It is suggested by the reference and we are further informed by Mr. O'Connor that no difficulty is apprehended in protecting the pipes, if so exposed, from wanton injury, and although pipes so exposed are almost unknown in England, they are by no means uncommon in thinly populated countries.

But many new difficulties are involved in the proposal to expose the pipes on the surface. For example, the expansion and contraction due to changes of temperature are very greatly increased. We think these difficulties can be entirely overcome, but we have not yet determined in detail upon the mode of their removal. Such determination depends upon the result of investigations which are now in progress, and we have therefore decided, to present this interim report, and to reserve for a further report our final recommendation as to whether the mains should or should not be laid above ground.

REGULATION OF FLOW ALONG THE AQUEDUCT.

In most sections of the aqueduct it fortunately happens that there is high ground at a short distance from the pumping engine (compared with the length of the section), from which the tank of the next pumping station may be supplied by gravitation. Up to that high ground the rising main must always be under the pressure due to the altitude and the friction. From this elevated point, however, the flow to the tank of the next pumping station will be by gravitation, and we have considered whether this gravitation length should be without stop valves, or whether, on the other hand, stop or other valves are required at the inlets to the pumping station reservoirs or at other points, for isolating portions of the main in case of accident, or for the purpose of obtaining ingress to the pipes. The former plan, which has been adopted in one or two cases in America, would be the most economical, for, as the pressure could never exceed that due to the hydraulic gradient, lighter pipes could be used for parts of the work. But we think that the advantages of stop valves are so considerable, when for the purpose of repairing leakages or otherwise it is desired to empty parts of the main, that it is better to make the pipes strong enough to stand the full head of water when at rest in the main, though the main will be worked with all the valves open, and the normal pressure will be that due to the elevation and hydraulic gradient only.

There is one section requiring special treatment. If the section between the second and third pumping stations were treated similarly to the rest, the closing of the stop valve at the third pumping station would place about 36 miles of the main under pressures of 450 to 650 feet. These pressures would be reduced by about 200 feet, if a reservoir were constructed on the high ground near the 33rd mile of the aqueduct, and we recommend that such a reservoir should be constructed. The depth of this reservoir should not be less than 25 feet. The greater its capacity the better, but it should not be less than 5,000,000 gallons.

The service reservoir at Coolgardie will be required not only to equalize the supply for the day and night consumption, but to provide a store of water for use in case of repair to the main being necessary. We think the capacity of this reservoir should not be less than 20 million gallons and that its depth should be as great as the site will reasonably permit.

The suction reservoirs at the pumping stations should have a capacity not less than two million gallons and a depth of at least 20 feet.

MATERIAL AND CONSTRUCTION OF PIPES.

In the reference to the Commission the use of cast iron is excluded, we think very properly, from consideration.

In comparison with steel there would be no advantage in using wrought iron, while there would certainly be many disadvantages.

A main of cement with a steel spiral embedded in the cement has been used for seven or eight years for water mains subject to light pressures.

The system which is patented, has been used for town supply in Venice and in Algeria, and for the water supply of the barracks at Maisons Alfort in Paris, in each case by French engineers, who report favourably upon it.

The cement surface of such pipes is excellent for hydraulic purposes. They can be made to stand, when new, working pressures of 100 feet or more, and if laid underground the cement would not doubt continue in a good state of preservation so long as the steel of the coils was not attacked by corrosion.

We visited Paris in order to see the method of manufacture of these pipes. We saw the whole process and tested two pipes under pressure. Two other pipes are being sent to us for further examination and test especially as to watertightness under different pressures. The result of these tests will be dealt with in our supplemental report. In the meantime, with our present knowledge, we do not recommend the use of these pipes.

The only other material which can be used for the Coolgardie main is mild steel, which should in our judgment have a tenacity of 25 to 28 tons per square inch, and an elongation of at least 16 per cent. in an 8-inch length. The longitudinal joints of such pipes may be (*a*) gas welded, (*b*) rivetted or (*c*) dovetailed.

MR. MEPHAN FERGUSON'S PIPE.

A steel pipe has been shown to us with a dovetailed longitudinal joint patented in Australia and elsewhere by Mr. Mephan Ferguson and termed a rivetless seam. This joint is made by swelling the longitudinal edges of the plate and bringing them together in grooves made in the opposite sides of a longitudinal bar. The bar is then closed by pressure upon the swollen edges of the plate. A pipe of this kind with two longitudinal joints was sent to Professor Unwin, from which strips with the joints in the middle of each were cut and tested. In the case of five out of six tests, the strips broke through the solid plate and not at the joint. The remaining test strip broke at the joint. It is obvious that the joint in the specimen pipe was practically as strong as the solid plate. Professor Unwin afterwards attended at Messrs. Gwynne's works and saw a similar piece of pipe tested by hydraulic pressure. The pipe was about four feet long, one-eighth inch thick, and twelve inches in diameter. It had two of the patent rivetless seams. An internal water pressure of 800lbs. per square inch was applied before the test was stopped by leakage at the ends, which had nothing to do with the construction of the pipe. Subsequently, about 850lbs. per square inch was got on the pipe before leakage at the ends again stopped the test. In a third test the pressure momentarily reached 900lbs. per square inch. The pipe was bulged, but there was no leakage at the longitudinal joints, and they did not appear to be injured, though the stress on the steel must have reached nearly 20 tons per square inch when the internal pressure of 900lbs. per square inch was applied. So far as it went the test was very satisfactory, but it would be desirable to test a considerable length of main made by such a machine as will be employed in practice in the manufacture of these pipes to ascertain whether the joint can be made uniformly strong and water-tight throughout its length. The patentee states that rivetless seam pipes of such sizes as will be required for the Coolgardie Aqueduct can be manufactured in lengths of about 27 feet.

We are of opinion, however, that if pipes with such joints can be manufactured on a large scale with the satisfactory results obtained on a small scale they would be particularly well suited for use in the Coolgardie aqueduct. They would probably be cheaper than rivetted pipes, there would be fewer points of possible leakage, and they would have less hydraulic resistance. We would, therefore, suggest to the Government that the Patentee should be approached with the view of some arrangement being made with him for trials of the system with such machinery as would be used in practice. It is quite possible that plates having the dovetail on both edges cannot be rolled with the necessary accuracy, or that some other practical difficulty may arise. Nothing but a trial on a considerable scale can decide whether the manufacture of these pipes can be carried on with practical success. Further, we think it desirable that if possible within the time available, a length of at least a mile of this pipe should be laid above ground, with such joints as the patentee proposes to use, and tested under water pressure.

Such pipes have not yet been made except on an experimental scale. Until they have been manufactured commercially, and tested in the way suggested, we are unable to make a recommendation that they should be used for the Coolgardie aqueduct. Until further information is available, it is necessary to assume in this interim report that the main will be constructed according to one or more of the well-known and long-tried methods.

SPIRAL RIVETTED PIPES.

Spiral rivetted pipes have been suggested for the main. We have fully considered the system, but it does not appear to have any advantage sufficient to warrant a recommendation that it should be used for the Coolgardie main.

WELDED PIPES.

Pipes with gas welded longitudinal joints are undoubtedly the best. They are stronger for a given thickness than rivetted pipes, and having a smooth surface, they present less interruption to the free flow of the water. But the immunity from possible leakage at joints is a still more important advantage. Per unit of length they are somewhat more expensive than rivetted pipes, but being about 30 per cent. stronger for equal diameter and thickness, it is actually cheaper to employ them wherever the necessary thickness of the rivetted pipe is at least ¼ inch; below which thickness welded pipes become difficult to manufacture of the required diameters.

We therefore recommend that those pipes which will be subject to the heavier pressures and which therefore require a thickness of ¼ inch or more, should have two gas-welded longitudinal joints, and that they be made in tubes of about 14 feet length, coupled into pipes of about 28 feet, by inserting a plain end of one tube into a socket formed on the other tube, the transverse joint being rivetted. Welded tubes can be manufactured of somewhat greater length, and it would be desirable that they should be as long as possible, because it would reduce the number of joints and the possible points of leakage. We understand, however, that lengths greater than 28 feet would be inconvenient for carriage on the Western Australian Railways.

RIVETTED PIPES.

The rivetted pipes should be made with only one longitudinal joint, each "ring" or "tube" being therefore formed of a single plate. The greater part of the aqueduct will consist of such pipes 28 inches to 30 inches diameter and $\frac{5}{16}$ inch thick, and the greatest length of the tubes of which such pipes are made up will be about 5 feet 6 inches.

The longitudinal joints should be double rivetted lap joints, and those of contiguous lengths should not fall in one line.

Each tube should be made of the maximum length that can be obtained from a single plate. These tubes should be single rivetted together into lengths convenient for transport. The question of the connection of these lengths will be dealt with in our final report. The tubes may be made of uniform diameter, butt-jointed, with single rivetted covering rings. This, however, involves two rows of rivets at each transverse joint, two circular joints to be caulked which can be caulked only at the outer edges, and special difficulty of caulking and rendering watertight where the ring covers the overlap of the longitudinal joints. As there are two other ways of making the transverse joints, either of which is less liable to these objections, we do not recommend butt-joints. One of these ways is to expand one end of each tube, thus forming a socket to receive the plain end of the next tube and to join the two by single rivetting. The other plan is to construct the tubes alternately of larger and smaller diameter, the diameters differing by twice the plate thickness. Each larger tube will then overlap the smaller tubes at either end and will be connected therewith by single rivetting.

Having regard to all the circumstances, we recommend that the rivetted pipes should be constructed of tubes of alternately larger and smaller diameter. In coming to this conclusion, we have, of course, considered the increased hydraulic resistance which we are satisfied is unimportant.

AS TO BENDS.

The necessary bends will have large radii, and may therefore be made by bevelling the ends of contiguous pipes. It is possible to arrange for all bends to be made by various numbers of pipes with standard bevels of $2\frac{1}{2}$, 5, $7\frac{1}{2}$ and 10 degrees.

THICKNESS OF PIPES.

The mains may be calculated for a working stress of $7\frac{1}{2}$ tons per square inch on the net section of the metal, with an allowance of 1-16 inch for corrosion and other contingencies.

For lap-welded mains it does not appear desirable that the thickness should be less than a $\frac{1}{4}$ inch. For less thickness the welding is difficult and the strength of the weld uncertain. The following table gives the thickness of welded main necessary for different heads:—

Welded Main.

Diameter in inches.	Thickness in inches.	
	$\frac{1}{4}$	$\frac{5}{16}$
	Greatest safe head in feet.	
26	560	746
27	539	718
28	520	692
30	485	647

In the case of the rivetted main the strength of a double rivetted joint, if well proportioned, is seven-tenths of the strength of the plate, or, in other words, its efficiency is 0·7. This being so, the above rule would give the following as the maximum heads for the various diameters and thicknesses of the rivetted main:—

Rivetted Main.

Diameter in inches.	Thickness.			
	$\frac{3}{16}$ in.	$\frac{1}{4}$ in.	$\frac{5}{16}$ in.	$\frac{3}{8}$ in.
	Greatest safe head in feet.			
26	260	395	527	660
27	252	381	508	636
28	245	368	490	613
30	220	340	458	572

From section No. 1 of the line showing the pumping stations and hydraulic gradients, it will be seen that a considerable portion of the main will not be subjected to a greater head than 200 feet, so that most of the length may be of $\frac{3}{16}$ inch steel with double rivetted longitudinal joints.

With respect generally to the jointing, it is important to bear in mind that gas welded longitudinal joints, if they pass the hydraulic test, will almost certainly continue water-tight. With rivetted joints, however, this is not so. Small leaks from under the lap, or past the rivets, exist initially or are developed in time by the straining actions on the pipes. By our recommendations we hope to reduce those straining actions to a minimum, but the greatest possible care must be taken to make the pipes water-tight before they leave the place of manufacture, and to caulk any leaks which may subsequently develop as soon as possible after they become visible.

PRESERVATION FROM CORROSION.

The corrosion of the main internally or externally is the most serious danger to which it is exposed, and it must be coated with asphalte in the most careful way possible.

In the process of rolling, the surface of the steel is changed to a magnetic oxide (commonly called "black oxide") which, although resisting corrosion itself, rapidly scales off. It is necessary that this scale should be completely removed by a bath of dilute sulphuric acid followed by a bath of lime water, immediately before the plates are rivetted up. This is successfully done in practice, and should be insisted upon. While still in the lengths required for shipment, the pipes should be dipped in a nearly boiling asphaltic composition both in England and immediately before being laid in Australia. This composition should be a natural asphalte containing a large proportion of bitumen, with so much heavy tar oil (creosote oil of commerce) added to it as may be necessary to produce when cold a smooth plastic and strongly adhesive varnish. The usual method with cast iron pipes is first to heat them in an open-topped funnel-shaped stove of brickwork, at the bottom of which is a fire. By this means the pipes are rarely heated uniformly. In the case of the Coolgardie pipes, special arrangements should be made for heating each length to a uniform temperature of about 300 degrees Fahrenheit. When so heated, the tubes should be dipped into the nearly boiling asphalte. Here again it is essential that special arrangements should be made; the fire is frequently allowed to impinge upon the plates of the bath, and thus, by the evolution of gases from the already viscous asphalte, to render the hottest portions more viscous still, so that they cease to circulate. These objections must be carefully avoided. The pipes should remain in the asphalte until they have fully acquired the temperature of the liquid, and should then be drawn out and allowed to cool while hanging in that position.

The dipping on the ground should follow as nearly as may be the conditions above described, and any parts of the pipe at which the coating is damaged by rivetting, caulking or otherwise, should be properly painted with a natural asphalte dissolved in bisulphide of carbon.

PROVING PIPES.

Before being dipped the pipes should be proved by hydraulic pressure, the test pressure in each case being such that the stress on the net section of material shall be 12 tons to the square inch.

VALVES.

There are used on mains of this kind stop valves, self-acting stop valves, automatic reflux valves, scour valves and air valves.

STOP VALVES.—These should be on the sliding sluice principle with double faces. It is not necessary that the valve opening should be of the same area as that of the main. The loss of head with a valve having an area equal to one-third that of the main, is so small that it is more than compensated for by the comparative lightness, ease of working, and economy in cost. The inlet and outlet to each valve should gradually taper from the size of the main to that of the valve. In mains of such length it is essential, however, that the valves should be so designed and constructed that the final closing is very slow. Stop valves are now satisfactorily made of slightly different patterns by different makers. It is only necessary to specify the general construction and suitable test pressures, and to require the makers to mention in their tender the weight of the valve as a whole, and weight and composition of the gunmetal parts, and to send a working sectional drawing of the valve. These stop valves will be required at the inlet to each reservoir, at the outlet of the pumps, at every important depression, and generally at distances apart not exceeding five miles.

SCOUR VALVES.—These should have openings of 9 ins. to 6 ins., according to the length of main commanded, and should be placed on pipes connected with the under side of the main at every depression. The scour pipes should be carried to points at which the water can be harmlessly discharged, and from which it cannot return to the line of main. Where a stop valve occurs, a scour valve will generally be required on either side of it.

SELF-ACTING VALVES.—These are of two kinds, viz., those which close when the velocity of the water becomes abnormal, and reflux valves, which close when the flow ceases or tends to reverse. Both forms are commonly and usefully employed in the case of long lengths of cast iron mains. The first kind, if properly designed and so constructed that the last part of the closing is done exceedingly slowly, will effectually shut off the supply without danger to the main when from any cause, as for example a burst in a pipe below, the velocity of the water is increased to an abnormal extent.

When a large cast iron pipe bursts, an opening is frequently made as large as the pipe itself. With mild steel pipes however no leakage is likely to occur at any one point of sufficient amount to greatly increase the velocity of the water, or to cause the very serious difficulties which the sudden discharge of the main would entail. Under these circumstances we think it unnecessary to introduce the complication of the first kind of self-acting valves, which close for abnormal flows. Reflux valves are, however, desirable at the inlet to each reservoir, and immediately above each pumping station. These should be multiple flap valves so designed as to have the smallest possible lift in order that the backward flow of the water may be checked before any harmful velocity is attained. The aggregate area of the openings should be at least half the area of the pipe.

AIR VALVES.—It is necessary to provide air valves at all summits of upward bends in the main to liberate the air, when charging the main, and to keep it free from air disengaged from the water flowing in the main or possibly from gas produced by decomposition of organic matters in the water. It is known to the Commission that serious difficulties have arisen in some cases from insufficient provision of air valves, or from the appliances provided not acting efficiently. Simple stop cocks were at one time used as air valves on the summits of water mains, but automatic air valves are now commonly used, and we are of opinion that such valves are necessary. The air valves should be in groups of three or four in one casing and of considerable discharging capacity. In the case of the Coolgardie main we think these should be metallic valves. They should be protected by a strong cover from the possibility of interference or injury, and the leakage should be led from them and not allowed to flow over the main. In the case of a steel main of this kind the valves have a second function to perform. If the pressure in the main falls below

atmospheric pressure, they will admit air and prevent a collapse of the main. The rapid emptying of lengths of the main would but for such a provision produce a vacuum in the main. In some cases the provision of air valves has been rendered inefficient in consequence of the air being carried past them by the flow of the water at more or less considerable velocity. We recommend, therefore, the provision of air domes at each rise consisting of 12-inch cast iron pipes 18 inches in depth with flanges fitted to the crown of the pipe. Immediately above such dome should be fixed a 3-inch stop valve, and above that the air valve proper. Instead of cutting a 12-inch hole in the main, it should be perforated with numerous smaller holes. In addition to this, at the most important summits, about sixteen in number we recommend enlargements of the main to about twice the normal diameter, thus forming chambers, in which the velocity of the water would be reduced, and where the air or gas could freely disengage itself from the water and escape by the air valves. The enlargement may be made by gradually tapering a length of main up to and away from the air valve.

With this report we send three drawings, Nos. 2, 3 and 4, showing a proper distribution of the various valves in two typical sections of the aqueduct.

SOME GENERAL CONDITIONS.

We think it important to avoid allowing the main at any point intermediate between the inlet and outlet of each section to rise within about 10 feet of the hydraulic gradient except near the inlets to the pumping station tanks, where it should not rise above that gradient, and to avoid this it will be necessary near the inlet to the tank, to lay the pipes considerably below the general level of the ground. Wherever the pipes are so laid one or more of the following precautions must be taken :—

a. The pipes must be laid in open trenches. *b.* The pipes must be laid in concrete. *c.* The pipes must be very considerably increased in thickness, or otherwise strengthened to resist the external earth pressure.

A combination of two, or all three, of these methods may be adopted as may be most suitable in each case, but this must be considered as the drawings are prepared.

THE STEAM PUMPING MACHINERY.

The amount of pumping required in the Coolgardie scheme is large and the price of coal in the Colony is high. But there is nothing exceptional in the sizes of engines required or in their arrangement, and we see no reason why the pumping should not be carried on in a perfectly satisfactory way and at a cost somewhat less than that assumed in the estimates which have been put before us in the Chief Engineer's Report.

With a view of getting definite information we obtained estimates from the principal makers of steam pumping machinery in this country, and we have also received an estimate from one of the most important firms in the United States which manufactures machinery of this kind. In asking for estimates, complete freedom was given to manufacturers as to the type of steam engines, pumps and boilers to be proposed by them. A tracing of the pipe line with the sites of the proposed pumping stations marked was supplied to them, but they were permitted to suggest any arrangements which they thought desirable. The estimates received are in some cases very carefully drawn up. As it appears to us necessary that tenders for the pumping machinery should be obtained on a more detailed specification of the requirements, it is not desirable that the proposals of the different makers should be discussed in this report.

THE TYPE OF ENGINE TO BE ADOPTED FOR THE COOLGARDIE SCHEME.—It is only proposed at present to have one line of main, and the cost of coal delivered at mean distance along the pipe line is given in Mr. O'Connor's estimate at 32s. a ton. Hence it is essential to adopt economical engines, and to provide in every way for efficient working throughout the twenty-four hours without stoppage or delay, and to take every possible precaution against risk of accident either to the engines or the main. As the whole cost of the pumping machinery, exclusive of buildings and foundations, will probably be less than one-sixteenth of the whole estimated cost of the scheme, there is no reason why the type of steam pumping machinery adopted should not be absolutely the best obtainable having regard to all the local conditions of the work to be done.

In our opinion the engines should be triple expansion engines with surface condensers. The boiler pressure should be from 150 to 180 lbs. per square inch, that is high enough to make triple expansion effective. We have considered the question and we think that the surface condensers may be worked by passing the pumped water through the condensers without unduly heating the water.

Direct acting engines without fly wheels would be very suitable for pumping into the exceptionally long mains of the Coolgardie aqueduct. Engines with fly wheels are also used safely for pumping directly into mains, expedients being adopted which minimise the risk of damage from the stored energy of a fly wheel when an accident happens to the main. But in drawing a specification for tenders it should be stated that if rotative engines are proposed a strong preference will be given to engines so arranged as to have a very uniform turning moment, and which, therefore, do not require fly wheels having a large amount of stored energy. The pumps should be arranged to give a fairly uniform discharge to lessen dependence on the cushioning of an air vessel between the pumps and the main. The makers should be invited to arrange safety appliances and to state fully what provision they have made against either a sudden increase of pressure due to an accidental obstruction in the main or a sudden relief of pressure due to bursting of the main or sudden opening of a scour valve. The makers should be required to state the duty of the engines in lbs. of steam per pump H.P. hour, and in lbs. of coal per pump H.P. hour, which they are prepared to guarantee under a penalty for every quarter of a pound of steam, and every tenth of a pound of coal by which the guarantee duty is diminished.

In our opinion each pumping station should be provided with three pumping engines, each capable of pumping 2½ million gallons against the head at that station. Two of these engines would be normally at work, and one in reserve. The pumping lifts in the plan we propose have been so arranged that only two sizes of pumping engine are required for all the different stations. This secures, besides facility of manufacture, the greatest possible interchangeability of parts in the engines and the greatest simplicity of management.

To obtain the highest possible economy of coal, engines of a rather complicated kind are necessary. We are of opinion that under the conditions of working in Western Australia it is desirable to sacrifice a little in economy of coal, if by doing so a material gain in simplicity of the engine can be obtained. Probably with such lifts as there are on the Coolgardie aqueduct it would be possible to have engines working with 14lbs. of steam per P.H.P. hour, or with 1·5 lbs. of coal per P.H.P. But such engines would necessarily be complicated engines. Without going so far, at this stage of the inquiry, as to say that such engines, if proposed by any manufacturer, should not be considered, we are of opinion that a simpler engine, working with 18lbs. of steam per P.H.P. hour, or 1·9lb. of coal per P.H.P. hour, will probably be more suitable.

The steam and coal consumption given above are, of course, the steam and coal consumption in trial conditions of working with very good coal, and exclusive of the steam consumption for working feed pumps and auxiliary machinery. In ordinary working, with variations of load, the consumption of steam and coal will necessary be somewhat greater.

The engines being surface condensing engines, the boilers will be fed chiefly with condensed steam. Hence there is no objection to adopting water tube boilers. Looking at the difficulties of transport, and the high steam pressure required for triple expansion engines, we are of opinion that Lancashire boilers would probably be more costly and less convenient than good water tube boilers. We do not, however, recommend water tube boilers of the small tube or torpedo boat type.

GENERAL ESTIMATE OF COST.

We estimate that, assuming the tubes are made up into lengths of about 30 feet in this country, the pipes, valves and engines may be delivered at Fremantle at a cost somewhat below that estimated by the Chief Engineer in his report dated 17th July, 1896.

In conclusion we desire to refer to our general statement at page 2, as to the practicability of the scheme, and to add that in such a case simplicity of construction and working are of unusual importance.

In some respects the undertaking will exceed in magnitude anything hitherto performed, but each of the nine sections will be complete in itself, and so long as water is supplied to any section by that immediately below it the problem presents no greater difficulty than that of pumping 5,000,000 gallons a day to a height of 300 feet at a distance of 24 miles and allowing it to gravitate again to a further distance of 40 miles.

The series of nine sections proposed having on the average a much smaller head and a much shorter pumping main than this, may, under the conditions we have proposed, be worked with very little risk of break-down even for an hour. The pumping at each station will be regulated by the depth of water in the reservoir from which the engines of that station draw their supply, and as that depth will depend upon the quantity pumped from the next station below, and so on down to No. 1 Station, no difficulty of regulation from No. 1 occurs. Where on the other hand any pumping station fails to maintain the rate of pumping of those below, the worst that can happen will be an overflow at the reservoir of that station and a corresponding reduction of supply at Coolgardie.

Each reservoir should be provided with a suitable water level recorder, by means of which the variation of level in the reservoir will be continuously registered. Each diagram may conveniently represent a week's working, and with the weekly series of nine such diagrams, together with certain engine diagrams, and the corresponding nine weekly diaries of the engine men before him, the engineer in charge will be in possession of such facts as would make any abnormal working, whether from accident or neglect of duty, at once apparent. While therefore the proper working of the whole system presents no difficulty, it is quite clear that it will require some simple and inexpensive organisation, without which the results of excellence or simplicity of design and workmanship may be rendered abortive.

We are, Sir,

Your obedient Servants,

JOHN CARRUTHERS,

GEORGE F. DEACON,

WILLIAM CAWTHORNE UNWIN.

Printed by Wightman Mountain and Andrews, Westminster, London.

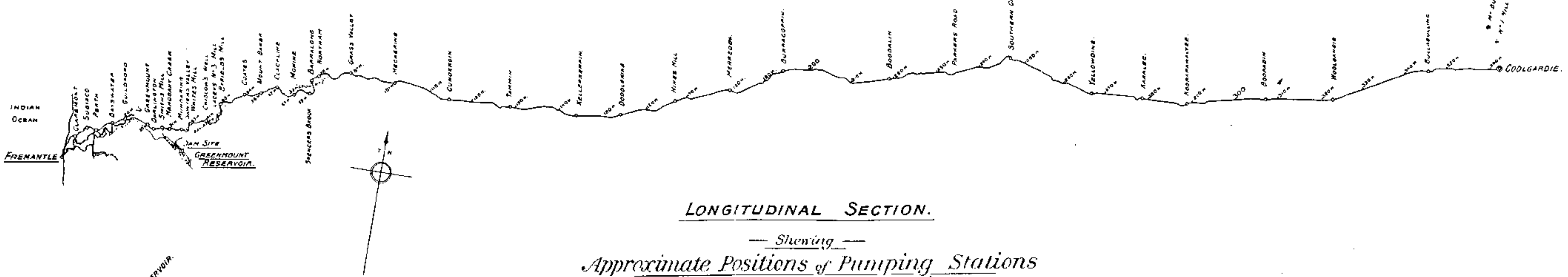
Coolgardie Water Supply.

1

General Plan.

To accompany Report of Commission dated August 3rd 1897.

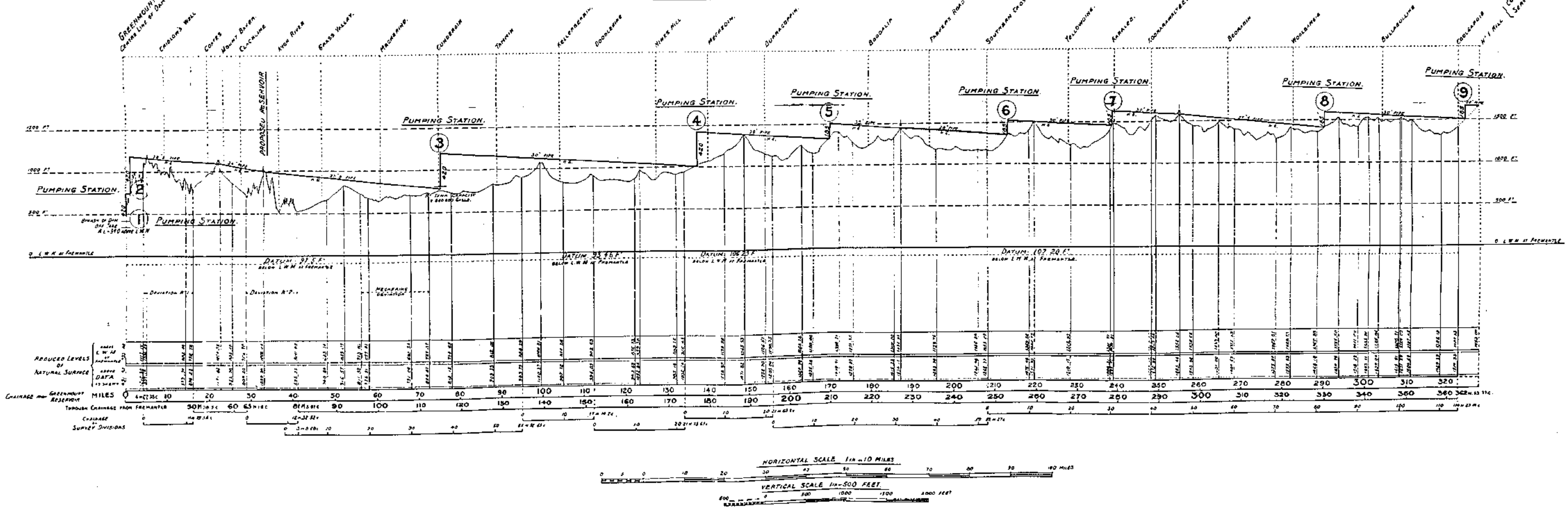
NOTE: The chainage given is the through chainage from Fremantle.



Longitudinal Section.

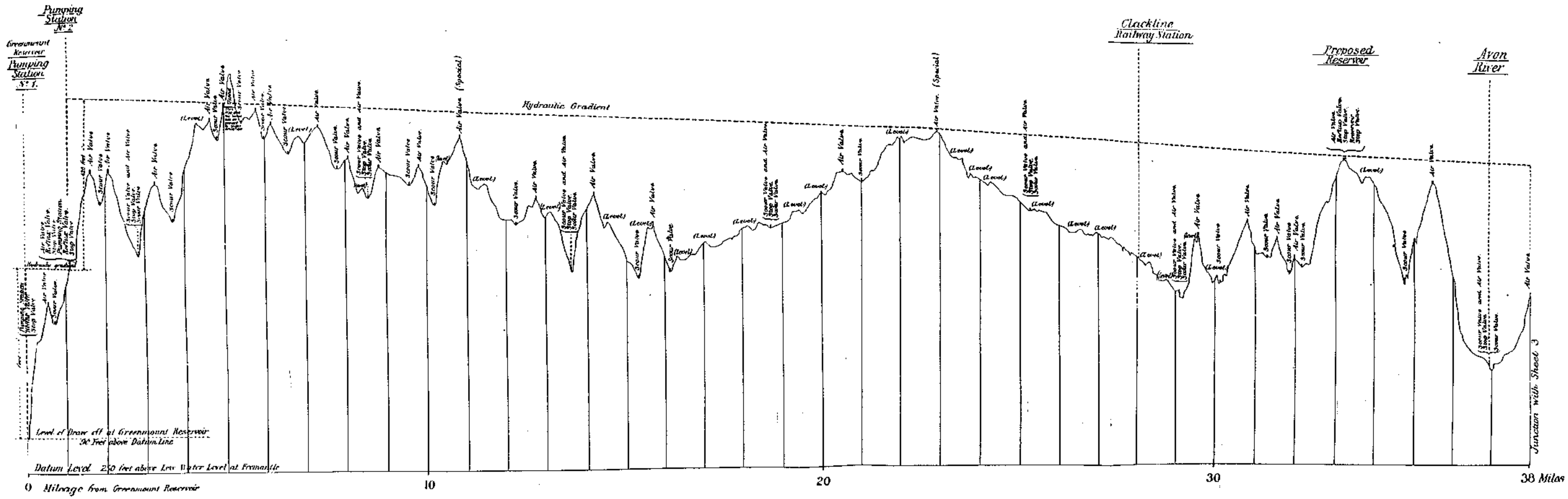
Showing

Approximate Positions of Pumping Stations and Diameters of Rivetted Pipes.



Sheet 2 Sections 1 and 2

Coolgardie Gold Fields Water Supply — Example of disposition of Valves referred to in Report of Commissioners



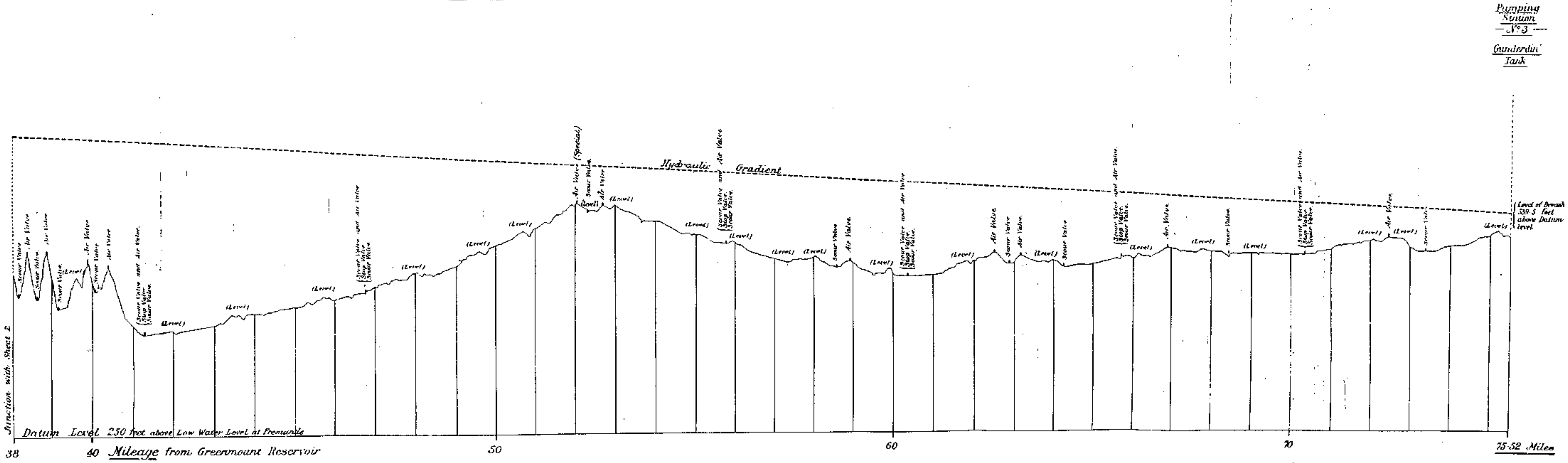
Note — The word (level) indicates a rise and dip which are to be equalized by cutting and embankment. The positions of the valves have been considered on large Scale Drawings.

The word (special) following the words "air valve" indicates a place in which the main should be enlarged under the air valve.

— Vertical Scale —
100 Feet to an Inch
Feet 100 0 100 200 300 400 500

Sheet (3) Section (2)

Coolgardie Gold Fields Water Supply — Example of disposition of Valves referred to in Report of Commissioners



Note. The word (Level) indicates a rise and dip which are to be equalized by cutting and embankment.
The positions of the valves have been considered on large Scale Drawings.

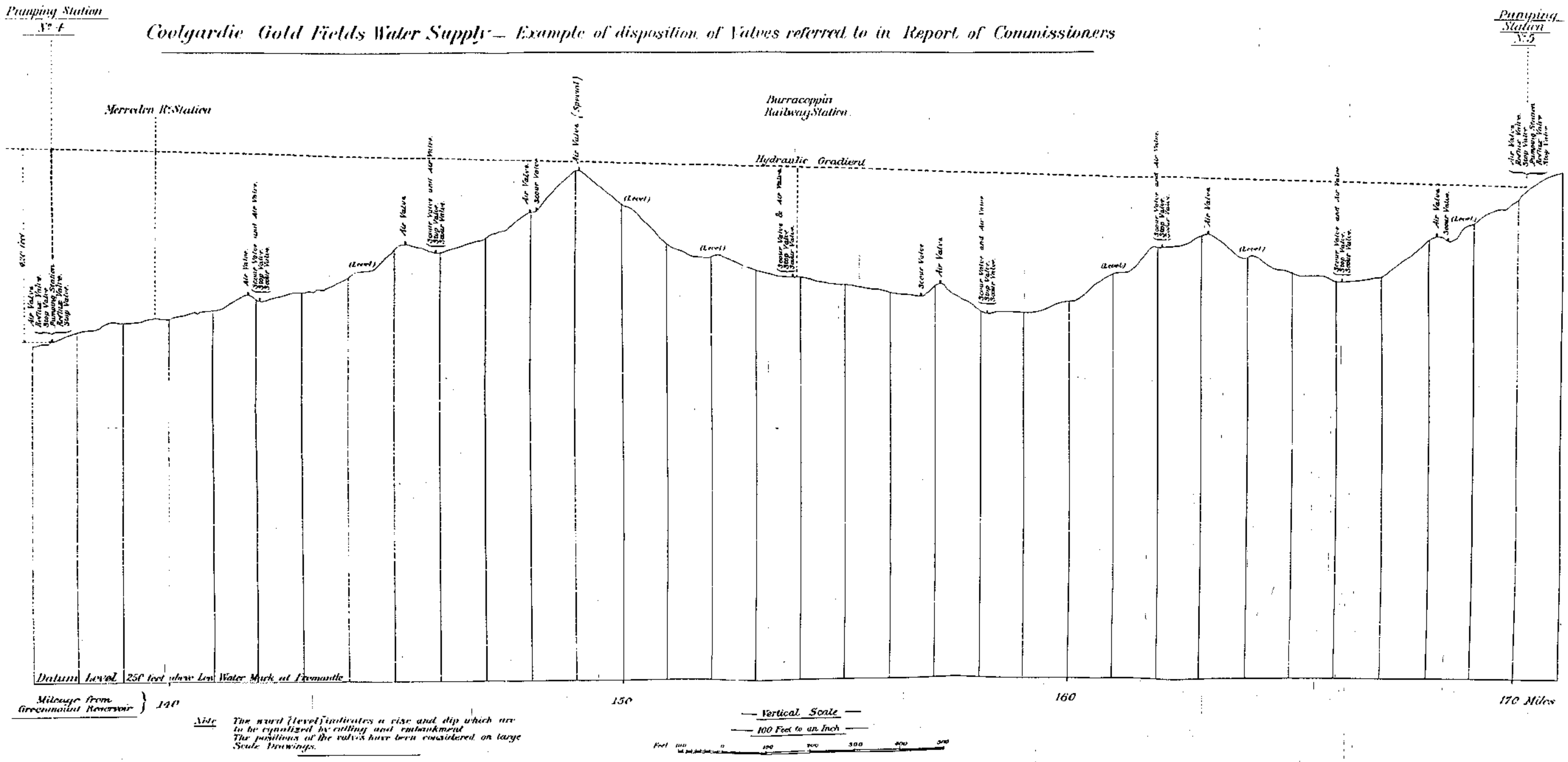
The word (special) following the words "air valve" indicates a place in which the main should be enlarged under the air valve.

— Vertical Scale —
— 100 Feet to an Inch —

Feet 100 0 100 200 300 400 500

Sheet 4 Section 4

Coolgardie Gold Fields Water Supply — Example of disposition of Valves referred to in Report of Commissioners



Note. The word (Level) indicates a rise and dip which are to be equalized by cutting and embankment. The positions of the valves have been considered on large Scale Drawings.

The word "(special)" following the words "air valve" indicates a place in which the main should be enlarged under the air valve.

COOLGARDIE GOLD FIELDS WATER SUPPLY.

Final Report of the Commission of Engineers appointed by the Government of Western Australia.

WESTMINSTER, 31*st December*, 1897.

The Agent-General for Western Australia, 15, Victoria Street, Westminster.

SIR,

COOLGARDIE GOLD FIELDS WATER SUPPLY.

We, the Commission appointed to inquire into the question of the Coolgardie Goldfields Water Supply, have the honour to submit our Final Report as follows:—

THE AQUEDUCT.—It was stated at page 5 of our Interim Report, of 3rd August, 1897, that the tables showing the positions and lifts of the pumps might be modified in the final report, and we submit a new longitudinal section showing the positions and lifts in the alternative scheme.

The hydraulic gradients of the aqueduct, and, therefore, the requisite power of the pumping engines depends on the diameters of the pipes, and these again are influenced by the size of the steel plates that can conveniently be rolled. We therefore had two plates rolled, the largest that could be obtained of ¼ inch thickness, and had them made up into two welded tubes, in one of which the length and in the other the breadth of the plates was made the length of the tube. The tubes were respectively 9 feet 4½ inches long by 29 inches internal diameter, and 7 feet 8 inches long by 32 inches internal diameter. It appeared from this trial that a tube of 29 inches diameter is the largest that can be practically obtained, when the width of the plate becomes the circumference of the tube, and we have on that account adopted 29 inches as the maximum diameter to be recommended for the welded pipes. In order to save freight, by nesting the pipes, and otherwise to reduce the first cost, we have, however, varied the gradient by introducing pipes of less diameter on parts of the aqueduct.

We propose that the portions of the aqueduct, subject to the lighter pressures, shall be constructed with rivetted pipes, the thickness of which will generally be $\frac{3}{16}$ inch. Plates of this thickness cannot be rolled so large as those above mentioned. In this case, therefore, the circumference of each tube made from a single plate will have to be equal to the length and not to the width of the plate, unless pipes less than 29 inches diameter be adopted. From estimates we have made of the relative costs of pipes of different diameters, we, however, find, when all the conditions affecting the problem are taken into account, that the most favourable diameter for the rivetted pipes is 31 inches. We have made no endeavour to provide for nesting such pipes into each other for shipment, as they will be more cheaply sent out as plates, either flat or only partly curved.

We have arranged and shown on the longitudinal section, gradients suitable to these diameters of pipes, together with the corresponding positions of the pumping stations, and the calculated lift at each station. The number of pumping stations, it will be observed, is, in this alternative arrangement, eight, of which four will have a lift of 406 feet each, and the other four a lift of 188 feet each, while the Interim Report recommended four stations with 420 feet lift, and five with 185 feet lift. This reduction in the number of pumping stations, and in the total lift cannot, of course, be obtained without increased cost of main, owing to larger pipes being required, often of greater thickness.

We find that the first cost of the alternative arrangement would probably be £70,000 to £80,000 more than that of the scheme as set forth in our Interim Report, but we believe that the reduced cost of pumping would, at least, balance the interest on additional capital. On the whole, we think the revised scheme is to be preferred, but we regard the question as one of financial policy rather than of engineering.

THE PUMPING ENGINES.—We have not considered it desirable to make more specific recommendations as to the type of engines which should be adopted than those in the Interim Report. Under certain conditions and in one particular, however, we propose to modify our recommendations. The Coolgardie Scheme is unique in this respect, that there will be eight pumping stations in series, the stoppage of any one of which will arrest the working of the whole line. It appeared to us that, with a minimum number of three engines at each station, there would be the greatest security against the complete stoppage of the working of the line. Two of the three engines working together would pump the full supply of 5,000,000 gallons per day, and the third would be a reserve engine. With this arrangement, which is that recommended in the Interim Report, each pump at each station would be for 2½ million gallons, while there would be two sizes of steam engines proportioned to the two different lifts respectively.

We do not propose to modify our former recommendations, should triple three-cylinder crank and fly-wheel engines be adopted. In the case, however, of tandem-coupled or duplex engines, each of which is really a pair of single engines, the arrangement, while still, in our opinion, the best for the 406 feet lifts, appears to be not quite so suitable or economical for the 188 feet lifts. We would, therefore, propose to allow the makers tendering the choice of using in the four stations of the alternative scheme with 188 feet lift, or in the five stations, of the Interim Report, with 185 feet lift, either two engines, one working and the other in reserve; or three engines, two working and one in reserve.

SIDERO CEMENT PIPES.—At page 6 of our Interim Report, we referred to a system of constructing pipes with a steel spiral embedded in cement, or more properly cement-mortar, for the composition is two parts by measure of sand to one of Portland cement. This mode of construction, if otherwise satisfactory, would possess some advantage where suitable sand could be readily obtained, and where the difficulties of conveyance are exceptional. The steel bars are of H section, about ⅝ inch deep, and, if brought to the ground in straight lengths, could be easily bent, by means of a simple machine to the required form. The suitability of such pipes for pressures up to a head of about 100 feet of water, had been strongly represented to us. We felt the issue to be so important, that, having seen the pipes manufactured in Paris,—where we tested two of them, and examined many others of different ages, we arranged with the patentee to send to London two pipes of full length, and a shorter piece for special examination and prolonged test. The internal diameter of the two pipes was about half a metre (19.68 inches) and the length of each about three metres (9.84 feet).

The leakage of the two pipes, when subjected to a steady head of water of about 20 feet, was very considerable, and nearly identical, but this leakage decreased rapidly at first and more slowly afterwards. With one of the pipes, the test was continued for 80 days, during which time the pressure was changed from 20 to 40, and finally to 50 feet. Our examination of the structure of these pipes, and the tests we have made, satisfy us that they are not suitable for any part of the Coolgardie main, but we do not express any opinion as to their suitability in other circumstances. The Coolgardie conditions are most exceptional, and each case should be considered on its merits.

POSITION OF MAIN ABOVE OR BELOW GROUND.—In our Interim Report, we indicated, under the head "General Statement as to the Practicability of the Scheme," at page 3, and under the head "Position of Main," at page 5, the great importance we attached to the question of leakage.

In any main, however constructed, some leakage is to be expected, and it is clear that the quantity of such leakage is likely to be in proportion to the length of the main. Small leakages from the joints and rivets of steel pipes, subject to the strains caused by expansion and contraction, are certain to occur. If detected early they are not difficult to cure, but, below ground, the individual cases are most difficult to detect until the flow is great enough to cause visible wetness at the surface, and before this occurs much damage may be done. We believe that the aggregate amount of leakage under such circumstances, in the Coolgardie main, 328 miles long, might be a serious proportion of the 5,000,000 gallons a day intended to be delivered at Coolgardie. For this reason we have given much consideration to the expediency of laying the mains above ground, where the slightest leakage might be at once detected and suppressed. But, above the ground, the range of temperature, and the consequent range of expansion and contraction, are much greater than a few feet below ground. If the main were rivetted up from end to end, as has been done in some cases, the straining action at the rivets and joints would be excessive. We have considered the expediency of using frequent lead joints, but, so exposed, we think they would cause considerable difficulty from leakage, and the cost would be greater than that of expansion joints at about every 120 feet.

EXPANSION JOINTS.—If the Coolgardie main is placed above ground, it is of the highest importance to have durable and efficient expansion joints. The amount of expansion to be provided for is large, about ⅝ of an inch per 100 feet length, for a change of temperature of 75 degrees Fahr. So far as we know, no case has previously occurred in which the general expansion of a water main has required to be met by an extensive use of expansion joints. We have, therefore, been driven to consider and to recommend what is essentially a new expedient in such a case. It appears that, with such a range of movement, some form of stuffing box joint must be adopted. After considering various forms, we have come to the conclusion that a joint on the principle of that used on the more recent Paris compressed air mains is well adapted to this purpose.* No form of expansion joint which has come under our notice, or which we have been able to devise, is simpler, cheaper, or likely to be more efficient than the Paris joint, although, so far as we can ascertain, it has not, up to the present time, been used for water mains, except for the joints of a 59-inch steel pipe, subject to a head of about 262 feet, recently constructed in connection with the water supply of Paris. The materials on which it depends have, however, been so used for a long time past, and we have no doubt whatever that a joint of this kind can be so designed as to be and remain perfectly watertight for such a time as would amply justify its adoption.

Such a joint was constructed at our suggestion by Mr. Cleminger, the representative of Mr. Mephan Ferguson, patentee of the seamless pipe. We saw this joint tested on one of the seamless pipes several times up to a pressure of 500 lbs. per square inch. It appeared so far to be quite satisfactory.

We next thought it necessary to carry out prolonged tests of the joint in such a manner that the movements due to expansion and contraction of the pipes would be imitated.

We send with this report a drawing and description of the joint so experimented with. It is substantially the same as that used in Paris.

The trials, which were carried out under the direction of Mr. Deacon, indicated that the details of the design could be improved, but notwithstanding some defects of the experimental apparatus, which on the whole were unfavourable to the endurance of the joint, the results of the trials as set out in appendix A are excellent, and, in our judgment, fully warrant the adoption of a joint on this principle.

The apparatus consisted of a 12 inch welded steel pipe, about 5 feet long, divided transversely into three pieces, the two end pieces being fixed, and the middle piece—3 feet long—being free to move axially to the extent of about ¾ inch. The joints shown and described on the drawing were placed round the open spaces between the three pieces. The pipe was charged with water maintained at a head of

*This joint is described in Reuleaux "Der Constructeur," 1869, as the joint of Normandy.

from 300 to 400 feet, and the central pipe was so connected with a steam engine that an approximately harmonic reciprocating motion in an axial direction, with periods of three to the minute, could be given to it.

We believe that if expansion joints are placed at every 120 feet in the Coolgardie pipes, the maximum annual motion which ought to be allowed for will not exceed $\frac{5}{8}$ inch, and we think that this range is only likely to occur if the pipes are emptied during extremes of local temperature. We, therefore, made $\frac{5}{8}$ inch the maximum range of motion at each joint, and we have imitated the smaller and more usual annual movements by ranges of about $\frac{3}{8}$ inch, and the diurnal movements in an exaggerated way, by ranges varying from $\frac{1}{4}$ to $\frac{1}{10}$ inch.

Four different qualities of vulcanized India-rubber were experimented with, and the general result was to show that the dearer qualities were not the best for this purpose. With medium qualities (see Tables 7 and 8), used in two rings, the full range of $\frac{5}{8}$ inch was repeated 990 and 1,420 times respectively before any leakage occurred, while 13,000 and 16,000 double strokes respectively, of $\frac{1}{4}$ inch were given with another quality of rubber of the same price, as shown by Tables 5 and 6, before any leakage occurred.

It is to be observed, moreover, that, on tightening up the bolts of the joints subjected to the $\frac{5}{8}$ inch strokes, in Tables 7 and 8, when the leakage amounted to about two drops per minute, they were further subjected to more than 13,000 double strokes of $\frac{5}{16}$ inch each, during and after which no leakage occurred. We are satisfied that the diurnal contraction and expansion will not amount to anything like $\frac{5}{16}$ inch, and we therefore think that this may be regarded as a very severe test of diurnal work. Severe tests, with strokes of mixed ranges, will be found in Tables 1 and 2.

The above observations apply exclusively to the two rubber rings encircling the two ends respectively of the central moving pipe. But, owing to the construction of the apparatus, the two joints themselves moved through smaller ranges, but more or less in proportion to the difference of recorded motions between the central pipe and the joint. In one of these, made with a ring of the lowest quality of rubber used, this motion of the joints in relation to the two fixed end pipes, varied (as shown in Table 9) from about $\frac{1}{4}$ inch to about $\frac{5}{16}$ during the first 2,500 strokes, and subsequently from about $\frac{3}{16}$ inch to $\frac{1}{8}$ inch throughout the remaining tests, covering 37,605 double strokes. The motion of the other ring (see Table 10), with the medium quality of rubber, varied from about $\frac{1}{4}$ inch to $\frac{5}{16}$ inch, during the first 2,500 strokes, and subsequently from about $\frac{3}{16}$ to $\frac{1}{8}$ inch throughout the remaining tests, covering 37.605 double strokes. During the whole 40,105 strokes, both these outer rings remained perfectly watertight, and were still watertight after the experiments had ended.

It is believed that, until leakage occurred, no sliding of the rubber took place, but that the whole of the displacement was satisfied by distortion of the rubber.

It must not, of course, be expected that the rubber will endure for the number of years corresponding with the number of repetitions of double strokes of the longer ranges, each of which was completed in one-third of a minute. Other elements will probably conduce to the deterioration of the rubber, before the mechanical strains to which it will be subjected cause the joint to leak. But it is one advantage of this joint that the replacement of the packing is not a very serious matter. Other advantages are the lateral flexibility of the joints, which permits of considerable angular movement of any two adjoining pipes, and the facility with which any length of pipe may be rapidly removed and replaced.

On the whole, we regard the result of these experiments as most satisfactory, but the larger joint required for the Coolgardie main must be carefully and specially designed. In the case of the rivetted pipes, a seating must be provided at the ends of the pipes to receive the expansion joints. This must be a steel ring with countersunk rivets.

Mode of Fixing the Main. — As the cost of the joint above described is by no means prohibitive, and as it is otherwise suitable, we think the principle of construction should be adopted, and that the pipes should be laid above ground. They may conveniently be supported on timber bolsters or sleepers, the upper sides of which would be hollowed to a depth of not less than 6 inches to fit the underside of the pipe.

So placed with the expansion joints at every 120 feet, the pipes would offer but little resistance to motion, and the action known as creeping may occur (due to the greater facility with which the metal can expand in one direction, as for instance, down-hill, than in the other), unless such action is designedly prevented. Again, in all curves the joints will have a tendency to move radially from the centre of the curve. For example, in the case of a 30 inch pipe, under a head of 400 feet, and having a radius of only 10 chains, there would be a radial thrust of about 9 tons on each length between the expansion joints, and, in the event of the sudden closing of a valve, the instantaneous pressure might be much higher. Moreover, it may be found that shorter radii than 10 chains are desirable in places.

It is essential that both the tendency to creep and the tendency to move under outward pressure at the curves should be effectually counteracted. The tendency to creep will certainly exist in some, if not all, of the pipes, and we are not satisfied that it may not exist also in the joints themselves, even if the pipes are prevented from creeping bodily. To prevent the creeping of the pipes, it is important that the middle of the length of each pipe should be prevented from moving axially, and this may be done by means of a mass of concrete, or by timber piles, holding a flange projecting from the underside of the pipe.

Creeping of the joints may be prevented by stops passing through the inner ring*, and projecting between the adjacent ends of the pipes, or by other means which will suggest themselves when the joints are designed in detail.

---

* In the joint actually tested this ring was of cast-iron. For the Coolgardie main it will probably be of wrought-iron.

We have next to consider the radial pressures tending, wherever the axes of adjoining pipes are not in a perfectly straight line, to cause the opening of joints by lateral displacement. At all curves this tendency should be resisted by abutments (which might be formed with timber piles or concrete blocks) on the outer side of the curves. The positions and numbers of such abutments will depend upon the pressures and radii, and will become the subject of future detail design.

There is a further contingency which must not be disregarded. Straight lengths are seldom quite straight, and there will always be a tendency at certain joints in nominally straight lengths to move laterally in one direction or another, and this tendency will be rendered more or less effective by the constant movements due to changes of temperature. This can be counteracted by fixing the sleepers nearest to the joints by means of short piles, or otherwise so as to prevent motion in a direction transverse to the line of pipe.

The next point requiring attention is the fixing of the stop valves and reflux valves. When such valves are closed, and the pressure on one side removed, the unbalanced pressure on the other side will often be 30, and in some cases more than 60 tons, with the liability to instantaneous pressures of greater amount. The valves must therefore be strongly fixed to the ground, and to this end it will be necessary to calculate the possible pressures in each case, and to make ample provision accordingly.

The various precautions we have indicated involve no complication; but the arrangements described, and the expansion joints, must be carefully considered and worked out in detail on the drawing board.

Proving the Main during Construction.—We think it desirable, if possible, to test the rivetted mains in sections during construction, otherwise a very large and unexpected delay may arise in caulking the leaks when the water is first laid on. To facilitate testing, it may be desirable to keep the erection of the pumping stations somewhat in advance of the construction of the mains, so that water may be pumped forward from any available source of supply.

Protecting the Main from Heat.—The actual amount of contraction and expansion will be largely affected by the colour of the pipes. They will at first have upon them the asphalte coating—a very poor reflector of heat—and this coating, unless otherwise protected, will soon dry and become brittle by exposure to sunshine, and lose those properties which cause it to adhere to the steel. But we think that a coating of some kind must be permanently maintained. There is nothing cheaper or better than lime-wash, with a proper proportion of size. It is a good reflector of heat, and will, therefore, greatly reduce the work to be done by the expansion joints. It will tend to preserve the iron from rust wherever it is properly maintained, and in the climate of Western Australia we do not think that such objections to its use, as would obtain in this country, will be found at all important in comparison with its advantages. The white-washing of these pipes might be economically done by the compressed air spraying process now extensively used for painting large surfaces.

CONCLUDING REMARKS.

In the course of our investigations, and while recording our conclusions in this and our former report, we have been impressed from time to time with the necessity for drawing attention to the large part which the treatment of details must play in the degree of success attained. We have stated our conclusions as to the general arrangement and design of the larger elements of this remarkable aqueduct, and have dealt with the principles of construction of certain essential details, but there remains a large amount of no less important work which can only be properly done in the course of writing the specifications and preparing the drawings, and this work will devolve upon the engineers responsible for the undertaking.

In conclusion, we record with satisfaction the fact that each step marking the results of our deliberations expresses our unanimous opinion. It was by no means clear that this would be so at first; but, where doubts arose, they were in every instance removed by further enquiry and consideration.

We are, Sir,

Your obedient Servants,

JOHN CARRUTHERS.

GEORGE F. DEACON.

WILLIAM CAWTHORNE UNWIN.

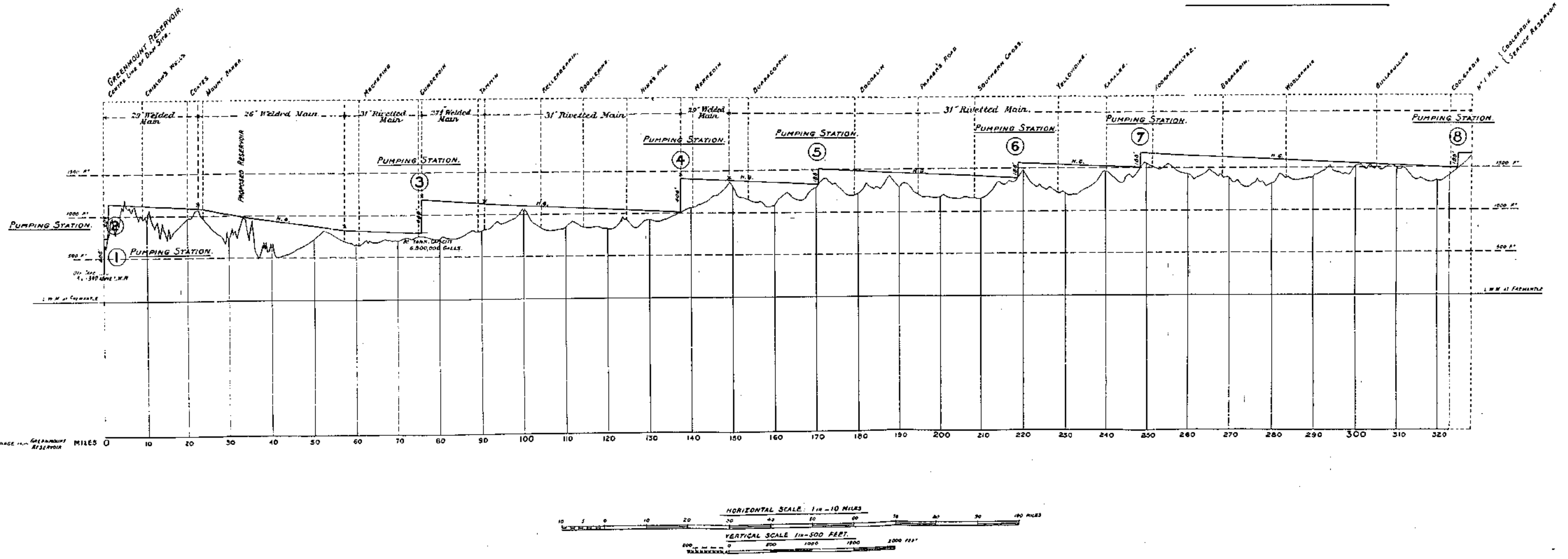
Coolgardie Water Supply.

LONGITUDINAL SECTION.

Shewing

Revised Approximate Positions of Pumping Stations and Diameters of Pipes.

To accompany Final Report of Commission dated 31st December 1897.



Appendix A.

EXPERIMENTS CONCERNING THE ENDURANCE OF VULCANIZED INDIA-RUBBER EXPANSION JOINTS ON A 12-INCH PIPE, CONSTRUCTED IN ACCORDANCE WITH DRAWING No. X.

In each experiment there were two fixed lengths of pipe in the same straight line, with their nearest ends 3 feet apart. The space between them was filled by a third pipe, capable of movement axially to the extent of one inch. The two spaces between the two fixed and the one movable pipe were covered by cast iron collars; each collar had two junk rings, between each of which and the collar an india-rubber ring was placed. The junk rings were connected by bolts, by means of which the rubber could be compressed against the pipes. During the experiments, the movable pipe was racked axially by levers driven by steam, the motion being approximately harmonic. The period of each double stroke was three minutes. A water pressure of 200 lbs. per square inch was maintained within the pipes throughout the experiments, except when great leakage occurred. When the apparatus was not at work, the pressure was not maintained.

The outer junk rings of each joint were strutted apart, and otherwise fixed, so that the motion was nearly confined to a single ring in each joint. The two working rings are distinguished as A and B, and the lengths of strokes recorded are the actual motions of the moving pipe in relation to the inner junk rings. Although the outer junk rings were subject to continuous slight movements, and the same rings were used under them from beginning to end of the whole series of experiments, no leakage occurred.

Until leakage occurred, there is strong reason to believe that no sliding of any of the rings took place, but that they were merely distorted.

The maximum pressure required to move the central pipe in a $\frac{5}{8}$ inch stroke, when a joint had been tightened up in consequence of leakage with a 15 inch spanner, and was perfectly watertight, was 5.2 tons. It is believed that throughout the experiments no joint, until after being tightened up in consequence of leakage, caused half this resistance to motion.

The accompanying diagram shows that the pressure required was proportional to the travel from the central position in which the rubber was not laterally strained.

Table No. 1. Experiment No. 1.

JOINT **A** (inner ring).

Racking began at 2.5 p.m. on the 2nd September, 1897, and ended at 10 a.m. on the 7th September, 1897, having been carried on during working hours only.

Condition of Rubber Joint.	Numbers and lengths of strokes.	Aggregate numbers of double strokes at which each change occurred.	Remarks.
New rubber ring	—	—	Dark vulcanized rubber. Price 3/6* per lb.
Joint working well with no leakage during	1,695 double strokes of $\frac{1}{4}$ in. & 465 double strokes of $\frac{9}{16}$ in.	—	Manufacturer's description:—"D."
Joint began to leak at about 2 drops per minute at	—	2,160	
Leaks gradually increasing during...	180 double strokes of $\frac{9}{16}$ in.	—	Specific gravity, 1·46
Joint tightened up. Leak almost stopped at	—	2,340	
Leaks gradually increasing during...	75 double strokes of $\frac{9}{16}$ in. 300 ,, ,, $\frac{11}{16}$ in. 2,070 ,, ,, $\frac{5}{8}$ in.	—	
Rapid leakage. Ring removed for examination	—	4,785	

* All the prices quoted for India-rubber are subject to a discount of about 25 per cent.

TABLE No. 2. EXPERIMENT No. 1.

JOINT B (inner ring).

Racking began at 2.5 p.m. on the 2nd September, 1897, and ended at 10 a.m. on the 7th September, 1897, having been carried on during working hours only.

Condition of Rubber Joint.	Numbers and lengths of strokes.	Aggregate numbers of double strokes at which each change occurred.	Remarks.
New rubber ring	—	—	Drab vulcanized rubber. Price 4/6 per lb.
Joint working well with no leakage during	1,695 double strokes of $\frac{1}{4}$in. 720 ,, ,, $\frac{9}{16}$in. 300 ,, ,, $\frac{11}{16}$in. 15 ,, ,, $\frac{5}{8}$in.	—	Manufacturer's description :— "*Drab Deckle.*" Specific gravity, 1·63
Joint began to leak at about 2 drops per minute at	—	2,730	
Leaks gradually increasing during ...	1,185 double strokes of $\frac{5}{8}$in.	—	
Joint tightened up. Leaks almost stopped at	—	3,915	
Leaks gradually increasing during ...	870 double strokes of $\frac{5}{8}$in.	—	
Rapid leakage. Ring removed for examination	—	4,785	

TABLE No. 3. EXPERIMENT No. 2.

JOINT A (inner ring).

Racking began at 2.30 p.m., on the 7th September, 1897, and ended at 2.55 p.m., on the 9th September, 1897, having been carried on during working hours only.

Condition of Rubber Joint.	Numbers and lengths of strokes.	Aggregate numbers of double strokes at which each change occurred.	Remarks.
New rubber ring	—	—	Dark vulcanized rubber. Price 6/6 per lb.
Joint working well with no leakage during	1,035 double strokes of $\frac{5}{8}$in.	—	
Joint began to leak at about 2 drops per minute at	—	1,035	Manufacturer's description :— "*A.*"
Leaks gradually increasing during ...	865 double strokes of $\frac{5}{8}$in....	—	
Joints tightened up. Leakage only slightly reduced at	—	1,900	Specific gravity, 1·03
Leaks gradually increasing during ...	1,415 double strokes of $\frac{5}{8}$in.	—	
Rapid leakage. Ring removed for examination	—	3,315	

TABLE No. 4. EXPERIMENT No. 2.

JOINT **B** (inner ring).

Racking began at 2.30 p.m. on the 7th September, 1897, and ended at 2.55 p.m. on the 9th September, 1897, having been carried on during working hours only.

Condition of Rubber Joint.	Numbers and lengths of strokes.	Aggregate numbers of double strokes at which each change occurred.	Remarks.
New rubber ring	—	—	Dark vulcanized rubber. Price 6/6 per lb.
Joint working well with no leakage during	1,725 double strokes of $\frac{5}{8}$in.	—	
Joint began to leak about 2 drops per minute at	—	1,725	Manufacturer's description :— "*A*."
Leaks gradually increasing during ...	180 double strokes of $\frac{5}{8}$in.	—	
Joints tightened up. Leakage only slightly reduced at	—	1,905	Specific gravity, 1·03
Leaks gradually increasing during ...	1,410 double strokes of $\frac{5}{8}$in.	—	
Rapid leakage. Ring removed for examination	—	3,315	

TABLE No. 5. EXPERIMENT No. 3.

JOINT **A** (inner ring).

Racking began at 7.15 a.m. on the 10th September, 1897, and ended at 4.0 p.m. on the 23rd September, 1897, having been carried on during working hours only.

Condition of Rubber Joint.	Numbers and lengths of strokes.	Aggregate numbers of double strokes at which each change occurred.	Remarks.
New rubber ring	—	—	Drab vulcanized rubber. Price 4/6 per lb.
Joint working well with no leakage during	13,245 double strokes of $\frac{11}{32}$in.	—	
Joint began to leak at about 2 drops per minute at	—	13,245	Manufacturer's description :— "*Drab Deckle.*"
Leaks gradually increasing during ...	3,510 double strokes of $\frac{11}{32}$in.	—	
Sudden increase in leakage to a rapid dropping at	—	16,755	During this experiment the bolts were not tightened.
Leaks gradually increasing during ...	670 double strokes of $\frac{11}{32}$in.	—	
Rapid leakage. Ring removed for examination	—	17,425	Specific gravity, 1·63

TABLE No. 6. EXPERIMENT No. 3.

JOINT B (inner ring).

Racking began at 7.15 a.m. on the 10th September, 1897, and ended at 4 p.m. on the 23rd September, 1897, having been carried on during working hours only.

Condition of Rubber Joint.	Numbers and lengths of strokes.	Aggregate numbers of double strokes at which each change occurred.	Remarks.
New rubber ring	—	—	Drab vulcanized rubber. Price 4/6 per lb.
Joint working well with no leakage during	16,800 double strokes of $\frac{11}{32}$in.	—	
Joint began to leak at about 2 drops per minute at	—	16,800	Manufacturer's description :—"*Drab Deckle.*"
Leaks gradually increasing during ...	525 double strokes of $\frac{11}{32}$in.	—	During this experiment the bolts were not tightened
Sudden increase in leakage to a rapid dropping at	—	17,325	
Leaks gradually increasing during ...	100 double strokes of $\frac{11}{32}$in.	—	
Rapid leakage. Ring removed for examination	—	17,425	Specific gravity, 1·63

TABLE No. 7. EXPERIMENT No. 4.

JOINT A (inner ring).

Racking began at 12.0 a.m. on the 24th Sept., 1897; it was stopped at 11.0 a.m. on the 25th Sept., 1897; it was started again at 12.0 a.m., on the 7th Oct., 1897, and ended at 8.30 a.m. on the 16th Oct., 1897, having been carried on during working hours only.

Condition of Rubber Joint.	Numbers and lengths of strokes.	Aggregate numbers of double strokes at which each change occurred.	Remarks.
New rubber ring	—	—	Dark vulcanized rubber. Price 4/6 per lb.
Joint working well with no leakage during	990 double strokes of $\frac{5}{8}$in....	—	
Joint began to leak at about 2 drops per minute at	—	990	Manufacturer's description :—"*Black Deckle.*"
Leak gradually increased during ...	540 double strokes of $\frac{5}{8}$in....	—	
Joint tightened up and leak stopped at	—	1,530	Specific gravity, 1·64
Joint working well with no leakage during	13,050 double strokes of $\frac{5}{16}$in.	—	
Racking ended. No leakage. Ring removed for examination... ...	—	14,580	

TABLE No. 8. EXPERIMENT No. 4

JOINT **B** (inner ring).

Racking began at 12.0 a.m., on the 24th September, 1897 ; it was stopped at 11.0 a.m. on the 25th September, 1897 ; it was started again at 12.0 a.m. on the 7th October, 1897, and ended at 8.30 a.m. on the 16th October, 1897, having been carried on during working hours only.

Condition of Rubber Joint.	Numbers and lengths of strokes.	Aggregate numbers of double strokes at which each change occurred.	Remarks.
New rubber ring	—	—	Dark vulcanized rubber. Price 4/6 per lb.
Joint working well with no leakage during	1,420 double strokes of $\frac{3}{8}$in.	—	Manufacturer's description :—
Joint began to leak slightly (no dropping) at	—	1,420	"*Black Deckle.*"
Leak gradually increased, but did not cause dropping during ...	110 double strokes of $\frac{5}{8}$in. ...	—	
Joint tightened up and leak stopped at	—	1,530	
Joint working well, with no leakage during...	13,050 double strokes of $\frac{5}{16}$in.	—	Specific gravity, 1·64
Racking ended. No leakage. Ring removed for examination ...	—	14,580	

TABLE No. 9. EXPERIMENTS Nos. 1, 2, 3 & 4.

JOINT **A** (outer ring).

From beginning to end of the experiments this joint showed no sign of leakage.

(The relative motion of the joint and fixed pipe at this ring was not intentionally given, but was a consequence of the elasticity of the parts of the apparatus.)

Racking began	at 2.5 p.m.	on the 2nd Sept.,	and ended	at 10 a.m.	on the	7th Sept., 1897.
,, began again	at 2.30	,, 7th ,,	,,	2.55 p.m.	,,	9th ,,
,, ,, ,,	7.15	,, 10th ,,	,,	4.0 ,,	,,	23rd ,,
,, ,, ,,	12.0 noon	,, 24th ,,	,,	11.0 a.m.	,,	25th ,,
,, ,, ,,	12.0 ,,	,, 7th Oct.,	,,	8.30 a.m.	,,	16th Oct., 1897.

Having been carried on during working hours only.

Condition of Rubber Joint.	Numbers and lengths of strokes.	Aggregate numbers of double strokes at which joint was disturbed.	Remarks.
New rubber ring	—	—	Dark vulcanized rubber. Price 3/6 per lb.
Joint moving considerably more at top than at bottom during ...	2,500 double strokes varying from a maximum of about $\frac{5}{16}$in. to a minimum of about $\frac{1}{8}$in.	—	Manufacturer's description :— "*D.*"
Joint refixed to reduce movement at	—	2,500	The lengths of strokes as given are the approximate means
Joint working during	2,285 double strokes of about $\frac{1}{8}$in.	—	of the relative motions of fixed
Rubber ring disturbed for insertion of new ring on inner side of joint at	—	4,785	pipe and cast-iron
Joint working during	3,315 double strokes of about $\frac{1}{16}$in.	—	junk ring at three points equiangular from the centre of the pipe.
Rubber ring again disturbed for insertion of new ring on inner side of joint at	—	8,100	
Joint working during	17,425 double strokes of about $\frac{1}{16}$in.	—	
Rubber ring again disturbed for insertion of new ring on inner side of joint at	—	25,525	Specific gravity, 1·46
Joint working during	1,530 double strokes of about $\frac{1}{16}$in.	—	
Joint very much tightened for the purpose of reducing leakage at inner ring at	—	27,055	
Joint moving more at the top than at the bottom during ...	13,050 double strokes of about $\frac{1}{8}$in.	—	
Racking ended. Ring removed for examination	—	40,105	

TABLE No. 10. EXPERIMENTS Nos. 1 2 3 & 4.

JOINT B (outer ring).

From beginning to end of the experiments this joint showed no sign of leakage.

(The relative motion of the joint and fixed pipe at this ring was not intentionally given, but was a consequence of the elasticity of the parts of the apparatus).

Racking began at 2.5 p.m. on the 2nd September, and ended at 10 a.m. on the 7th September, 1897.
„ began again „ 2.30 „ 7th „ „ 2.55 p.m. „ 9th „
„ „ „ „ 7.15 „ 10th „ „ 4.0 „ „ 23rd „
„ „ „ „ 12.0 noon „ 24th „ „ 11.0 a.m. „ 25th „
„ „ „ „ 12.0 noon „ 7th October, „ 8.30 „ „ 16th October, 1897.
Having been carried on during working hours only.

Condition of Rubber Joint.	Numbers and lengths of strokes.	Aggregate numbers of double strokes at which joint was disturbed.	Remarks.
New rubber ring	—	—	Drab vulcanized rubber. Price 4/6 per lb.
Joint moving considerably more at top than at bottom during ...	2,500 double strokes varying from a maximum of about $\frac{5}{16}$in. to a minimum of about $\frac{1}{8}$in.	—	Manufacturer's description :— "*Drab Deckle.*"
Joint refixed to reduce movement at	—	2,500	
Joint working during	2,285 double strokes of about $\frac{1}{16}$in.	—	The lengths of strokes as given are the approximate means of the relative motions of fixed pipe and cast iron junk ring at three points equiangular from the centre of the pipe.
Rubber ring disturbed for insertion of new ring on inner side of joint at	—	4,785	
Joint working during	3,315 double strokes of about $\frac{1}{16}$in.	—	
Rubber ring again disturbed for insertion of new ring on inner side of joint at	—	8,100	
Joint working during	17,425 double strokes of about $\frac{1}{16}$in.	—	
Rubber ring again disturbed for insertion of new ring on inner side of joint at	—	25,525	Specific gravity, 1.63
Joint working during	1,530 double strokes of about $\frac{1}{16}$in.	—	
Joint very much tightened for the purpose of reducing leakage of inner ring at	—	27,055	
Joint moving more at the top than at the bottom during	13,050 double strokes of about $\frac{1}{16}$in.	—	
Racking ended. Ring removed for examination	—	40,105	

Printed by WIGHTMAN MOUNTAIN & ANDREWS, Westminster, London.

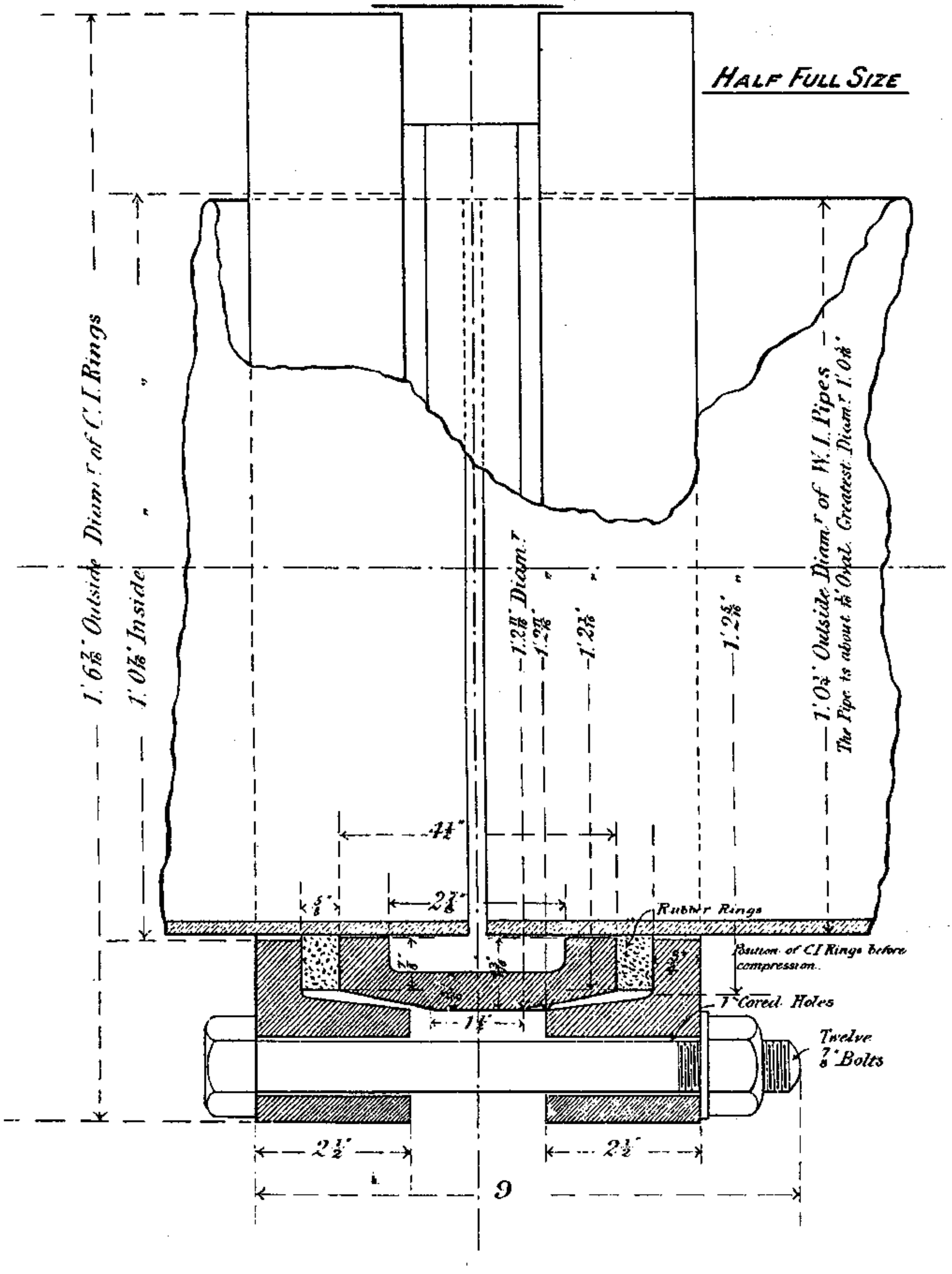
Coolgardie Water Supply.

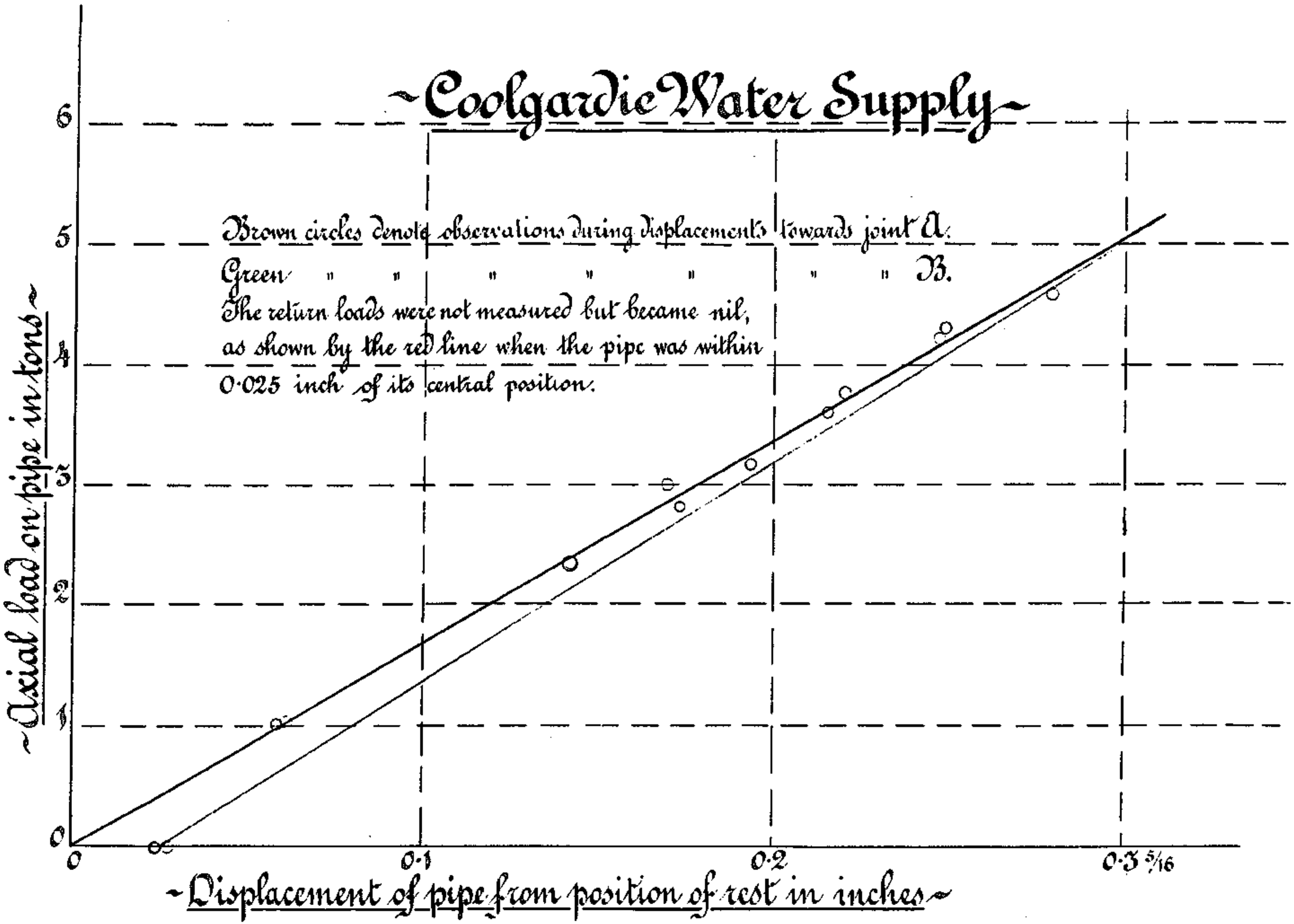
Half Sectional Elevation

of

Expansion Joint

Referred to in Final Report of Commission.
Dated 31st December, 1897.





~Coolgardie Water Supply~
Brown circles denote observations during displacements towards joint A.
Green " " " " " " " B.
The return loads were not measured but became nil, as shown by the red line when the pipe was within 0·025 inch of its central position.
~Axial load on pipe in tons~
0
1
2
3
4
5
6
0
0·1
0·2
0·3 5/16
~Displacement of pipe from position of rest in inches~

Appendix 3

COMPLETE TEXT OF C. S. R. PALMER'S PAPER TO THE INSTITUTION OF CIVIL ENGINEERS, MARCH 1905

COOLGARDIE WATER-SUPPLY

BY

CHARLES STUART RUSSELL PALMER,
M. Inst. C.E.

WITH AN ABSTRACT OF THE DISCUSSION UPON THE PAPER.

EDITED BY

J. H. T. TUDSBERY, D.Sc., M. Inst. C.E.,
SECRETARY.

By permission of the Council.
Excerpt Minutes of Proceedings of The Institution of Civil Engineers.
Vol. clxii. Session 1904–1905. Part iv.

LONDON:
Published by the Institution,
GREAT GEORGE STREET, WESTMINSTER, S.W.
[Telegrams, "Institution, London." Telephone, "Westminster 51."]
1905.

ADVERTISEMENT.

The Institution as a body is not responsible either for the statements made, or for the opinions expressed, in the following pages.

LONDON: PRINTED BY WILLIAM CLOWES AND SONS, LIMITED, DUKE STREET, STAMFORD STREET, S.E., AND GREAT WINDMILL STREET, W.

SECT. I.—MINUTES OF PROCEEDINGS.

28 March, 1905.

Sir GUILFORD L. MOLESWORTH, K.C.I.E., President, in the Chair.

(*Paper No. 3516.*)

"Coolgardie Water-Supply."

By CHARLES STUART RUSSELL PALMER, M. Inst. C.E.

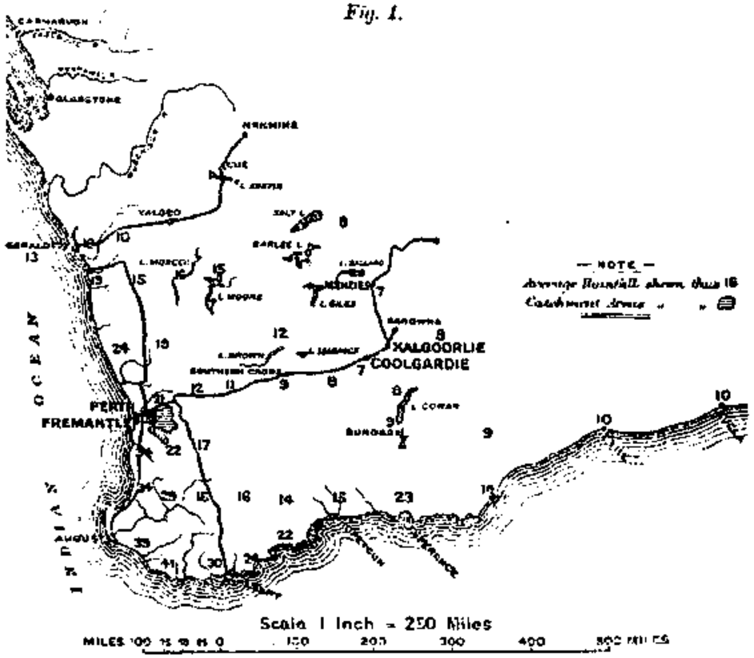
BEFORE proceeding to describe in this Paper the design and construction of the works undertaken for the water-supply of the Coolgardie district of Western Australia, it is necessary to touch briefly upon the history and topography of the district.

Since the discovery of the great inland goldfield of Coolgardie in 1892, the career of the State of Western Australia, which previously had made but slow progress, has been uniformly successful; for the resulting mining population created a profitable market for the agricultural and pastoral produce of the well-watered coastal country, which was therefore rapidly settled on as railway facilities were afforded. The town of Coolgardie is situated about 350 miles from the west coast and about 250 miles from the south coast (*Fig. 1*); and, although along the sea-shore and for a considerable distance inland this part of Australia is well watered, the portion—say, 300 miles by 250 miles—of the elevated tableland in the interior of which Coolgardie may be regarded as the centre is among the driest of the countries of the globe, the rainfall having been as little as 3½ inches in a year. Moreover, the surface soil generally is very porous and so excessively saline that, except in rock-holes after rain, really fresh natural water is practically unknown, although repeated boring has proved the existence here and there underground of small quantities of fairly potable water.

Coolgardie was discovered by pioneers who had pushed out, through this inhospitable country, for more than 200 miles from the terminus of the railway: they spread themselves over the length and breadth of the tableland already mentioned, discovering additional, though mostly smaller, goldfields. Their settlements,

however, were widely scattered, and the Government was soon faced with the serious problem of providing water for man and beast, not only at the mining-centres but also along the various tracks thereto. About £400,000 has been spent on smaller waterworks of every description, the exceeding dryness of the climate being soon made manifest by the poor result of each small but costly work carried out. It was thus proved that for any large supply of fresh water a source should be searched for elsewhere than on the surface or in the subsoil of any portion of this tableland

Fig. 1.



The seriousness of the problem can be gauged by the usual prices paid for water in later days. Even after completion of these smaller works, the prices were:—25*s.* per 1,000 gallons when the occasional rains filled the tanks which formed one class of the works, and £4 per 1,000 gallons when only water condensed from the extremely salt fluid obtained in wells and shafts was available.

Yielding to the pressure of popular opinion, the Government spent several thousand pounds without result, in a bore-hole more than 3,000 feet deep in solid granite; various schemes for condensing on a very large scale, at the salt lakes situated in the goldfields,

were abandoned on proof of the excessive salinity of the water of the lakes, the difficulty and cost of obtaining a sufficient supply of even this water, and the high price of fuel; and then two proposals for conservation, with sources comparatively near to the goldfields, were considered but abandoned, as the low rainfall rendered it more than questionable whether the yield would be sufficient. By a process of elimination, therefore, there was reached the accepted solution of the problem, namely, a source in the Darling Ranges bordering the well-watered west coast (Fig. 2, Plate 1). This scheme had the additional advantage that all intermediate townships, as well as the adjacent Government railway, could be supplied from the main conduit, the railway being especially benefited in its course through about 250 miles of arid country wherein railway water-supply was known to have cost as much as £60,000 in a single year.

Scope and Character of Adopted Scheme.—By the middle of 1895 the Government of Western Australia had decided that some large comprehensive scheme would be necessary; and, orders for report and recommendation having been issued, there were prepared, under the instructions of the late Mr. C. Y. O'Connor, C.M.G., M. Inst. C.E., the Author's late chief and predecessor in the position of Engineer-in-Chief of the State, thirty-one alternative proposals, from which, after study, three were chosen to be placed before the Government. The source of supply in each case was to be an impounding-reservoir in the Darling Ranges, whence the water was to be pumped in successive lifts to Mount Burgess, north of Coolgardie: thence it was to be reticulated to the various mining-centres, of which Coolgardie was one. In Mr. O'Connor's Report, the three schemes were stated,[1] for comparative purposes, to be as follows:—

"The result of . . . calculations went to show (as for steel pipes) that, for one million gallons daily, the cost would be from, say, £700,000 to £1,000,000, (depending upon the size of the pipe), and with cost of delivery varying from 5*s.* 6*d.* to 8*s.* 6*d.* per 1,000 gallons; while, for five million gallons daily, the cost varied from, say, £2,200,000 to £2,700,000 (depending similarly upon the size of the pipe), with cost of delivery varying from 3*s.* 5*d.* to 6*s.* 7*d.* per 1,000 gallons; and that, for ten million gallons daily, the cost varied from, say, £3,500,000 to £4,600,000 (depending similarly on the size of the pipe), with cost of delivery varying from 3*s.* to 5*s.* per 1,000 gallons."

The scheme adopted was for a daily supply of 5 million gallons, at a probable capital cost of £2,500,000, and a selling-price of 3*s.* 6*d.*

[1] "Report on Proposed Water-Supply (by Pumping) from Reservoirs in the Greenmount Ranges," p. 8. Perth, 1896.

per 1,000 gallons, after allowing for interest and depreciation. The consumption of the water provided by this scheme, which is still in its infancy, has not yet amounted to more than one-fourth of the quantity allowed for; and the Author reported to the Government, soon after becoming responsible, that until much greater development of mining occurs, the consumption is not likely to exceed one-half of that allowed for. It is therefore due to those originally responsible to point out that when the proposals were inaugurated, and, in fact, up to the time when the works were opened, no information and no authoritative opinion outside the Public Works Department could be obtained as to the probable consumption; while, on the other hand, there were the greatest expectations in the public mind of more extensive working of low-grade mines, when comparatively cheap water should be available. These expectations were not confined to the general public; for, some doubts having been expressed in Parliament as to the probability of so much as 5,000,000 gallons being used daily on the goldfields, a well-known firm offered to take that quantity daily for 20 years at 3*s.* 6*d.* per 1,000 gallons, provided that the Government would not compete with them in price. In September, 1896, Parliament sanctioned the raising of a loan of £2,500,000 for the construction of a storage-reservoir of about 5,000 million gallons capacity, a 30-inch line of steel main throughout, and a series of eight pumping-stations, with the necessary receiving-tanks and distributing-reservoirs.

In January, 1897, a Commission of English engineers—consisting of Mr. John Carruthers (the Consulting Engineer for the State in London), Dr. George F. Deacon and Professor W. C. Unwin—was appointed to inquire into and make recommendations as to the kind, thickness and size of pipe to be employed; whether it should be placed above or below ground; and the number, positions and power of the pumping-stations and engines, and the pumping and break-pressure reservoirs. Mr. O'Connor, who was then Engineer-in-Chief to the State, personally placed all available information before the Commission, which issued two reports. In the first or interim report nine pumping-stations were recommended, as indicated in Figs. 3, Plate 1. In the final report the Commission submitted an alternative arrangement, with eight pumping-stations in lieu of nine; and in the adopted scheme the locations of the pumping-stations differ but slightly from those of the first eight stations proposed by the Commission in their interim report: but it was possible to omit the ninth pumping-station, as it was decided to deliver the water into a large service-reservoir at

R. L. 1630, near Bulla Bulling (Figs. 4, Plate 1), instead of on a high hill near Coolgardie, and to increase the lift at each of the last four stations by such small amount as would enable this to be accomplished.

A further advantage obtained from the appointment of the Commission was that full knowledge of the proposed scheme was obtained by the Consulting Engineer, thus enabling him to give his advice when sought from time to time, to make recommendations as to pumping and other machinery, and to undertake inspection of the material and plant exported to the State.

The detailed description of the works will be divided under the following heads:—

I. The storage-reservoir and its catchment-area.
II. The construction of the weir.
III. The pipe-line.
IV. The pumping-machinery.
V. The pumping- and service-reservoirs, reticulation, etc.
VI. Cost of the works.

The following general outline is given here to facilitate a clearer understanding of the details.

General Outlines of Scheme.—A daily supply of 5,600,000 gallons was provided for, of which 5,000,000 gallons was for use in the goldfields, and the balance for waste and consumption *en route*. The supply is obtained from an artificial reservoir, having a capacity of 4,600 million gallons. From this reservoir the water is pumped through a steel conduit, 30 inches in diameter, by a series of eight pumping installations, to the main distributing-reservoir at Bulla Bulling, 308 miles from the main storage-reservoir and 1,290 feet above the lowest outlet-level of the latter. From the Bulla Bulling distributing-reservoir the water gravitates for 21 miles to the Coolgardie service-reservoir, and thence to the Kalgoorlie service-reservoir, a further 23½ miles, the total length of the conduit from the supply reservoir being 351½ miles (Figs. 4, Plate 1).

The first pumping-station is located on the right bank of the Helena River and 650 feet down-stream of the storage-reservoir. The pumps draw their water from a stand-pipe 4 feet in diameter, which is placed immediately in front of them and is fed by a 30-inch steel main, which, beginning at the outer valve-house, passes under the boiler-house before entering the stand-pipe. The pumps here lift the water a net height of 415 feet, through 1½ mile of pipe, and deliver it into a concrete receiving-tank having a capacity of 468,000 gallons and a depth of 15 feet of water.

The pumps at Station No. 2 draw their water from this receiving-tank, the maximum suction-lift being 11½ feet, and deliver it into a concrete regulating-tank at Baker's Hill, 22¼ miles from Station No. 2, the net lift being 340 feet. From the Baker's Hill regulating-tank, which is 15 feet deep and has a capacity of 500,000 gallons, the water gravitates to the West Northam regulating-tank, 12 miles distant. This tank is similar in construction to that at Baker's Hill, having the same capacity and depth. The net fall is 94 feet from Baker's Hill to West Northam, whence the water gravitates to the Cunderdin reservoir, a further 41 miles, thus making a total length of 75¼ miles between Stations 2 and 3. The Cunderdin reservoir has an available capacity of 10 million gallons. No. 3 pumping-station is located about ¾ mile from this reservoir, and the pumps draw their water from a stand-pipe, similarly to those at No. 1. The section between Stations Nos. 3 and 4 is 62¾ miles in length, the net lift at No. 3 being 215 feet. The water is delivered into a circular concrete tank at No. 4, having a capacity of 1 million gallons and a depth of 15 feet. From Station No. 4 the water is lifted a net height of 333 feet, and delivered through a section 32½ miles long into a rectangular concrete receiving-tank 20 feet deep, with a capacity of 1 million gallons. At Stations Nos. 5, 6, 7 and 8, the arrangements are similar to those at Station No. 4, and the receiving-tanks at Nos. 6, 7 and 8 are similar in design to that of No. 5, having also the same capacity and depth. The net lifts at Stations Nos. 5, 6, 7 and 8 are respectively 52 feet, 106 feet, 56 feet and 183 feet, and the corresponding lengths of section 46 miles, 31¾ miles, 45 miles and 12¼ miles. From Station No. 8 the water is delivered into a main service-reservoir at Bulla Bulling, of 12 million gallons capacity. Thence the water gravitates to Coolgardie, and from Coolgardie to Kalgoorlie. These towns are provided with circular concrete service-reservoirs, that at Coolgardie having a capacity of 1 million gallons and that at Kalgoorlie of 2 million gallons.

Early in 1898 the first work on the scheme, namely, construction of the branch line of railway to the weir, was put in hand, and was completed in the following August. In April of the same year, excavation for the foundations of the weir was started; concreting was begun in February, 1900, the first pumping took place in April, 1902, and the weir and subsidiary works were practically finished in April, 1903. Contracts for the pipes were let in October, 1898, and for the pumps in March, 1900. The excavation of the pipe-trench was begun in March, 1900. The laying and jointing of the pipes was begun in March, 1901; about 90 miles were completed that year and the remaining 260 miles (including the extension to Kalgoorlie) in 1902. The water reached Kalgoorlie in the middle of January, 1903, and the works were formally opened on the 26th of that month. The whole period of construction had thus been less than 5 years, although it was necessary to import all material for construction of the pipes, cement, valves and specials, lead for jointing, pumping-machinery, the ironwork in the weir, and much other material.

I.—The Storage-Reservoir.

When the scheme was first propounded, and, in fact, until shortly before the construction of the weir was begun, there were no river-gangings available: consequently, in judging of the probable inflow into a reservoir, it was necessary to base calculations on results obtained in other countries. About 3,000 square miles of the Darling Ranges having been examined, and thirteen possible sites surveyed in a preliminary manner, it was finally decided to place the reservoir at Mundaring on the Helena River, where the cost of construction per million gallons of storage would be least. Fig. 2, Plate 1, shows the catchment-area and the rainfall-records available; and notwithstanding that the catchment-area is 569 square miles in extent, it was decided to provide storage sufficient to meet 2 years' demand and loss.

On the face of it this was an excessive allowance, especially when it is considered that to fill this large reservoir there is required an off-flow of what would usually be considered a very small fraction—only 3 per cent.—of a rainfall of 18½ inches, which is less than the average of the minimum yearly precipitation at Mundaring and York. But the country in which the upper reaches of the Helena River are situated is formed of crystalline rocks, generally covered over large areas by ferruginous conglomerate, and, in a measure, by loamy sand, which in places extends to a depth of 20 to 30 feet below the surface. The conglomerate and sands generally overlie kaolinized granite, which, in turn, merges into solid granite. In the vicinity of the weir, the rock is more exposed, the country is less flat, and the ranges are better defined. The whole of the water-shed is thickly timbered with jarrah, red gum and wandoo, the jarrah predominating on the lower, and the wandoo on the upper reaches. Besides this heavy timber, the country is closely covered with an undergrowth of "blackboys" and other scrubby

plants. The actual yield from the catchment-area, therefore, is shown in the following Table, which gives the discharge of the Helena River since gauging was undertaken.

DISCHARGE OF HELENA RIVER AT WEIR-SITE.

Year.	Mean Rainfall Mundaring and York. Inches.	Discharge. Million Gallons.	Ratio of Discharge to Rainfall. Per Cent.
1897	24·5	672	0·34
1898	30·76	3,802	1·50
1899	27·17	1,857	0·83
1900	33·25	9,622	3·50
1901	25·0	1,401	0·69
1902	19·3	323	0·20

Not only are these figures very low, but the ratio of the discharge to the rainfall varies considerably more than does the rainfall. The small results as a whole can be accounted for partly by the absorptive nature of the soil of much of the catchment-area, therein differing from the catchment-areas usually available in other countries, and partly by the fact that the rain is precipitated very unfavourably: for although the annual fall, in the vicinity of the reservoir for instance, averages about 37 inches, it is spread over a period extending from about May to November, inclusive. During some months, it rains nearly every day; but only on very rare occasions does the fall exceed 1 inch in 24 hours, the average being less than ¼ inch, generally in light intermittent showers. The result is that the main watercourses do not begin to flow until 10 to 12 inches of rain have fallen, and they stop almost immediately the rainy season ends. The rainfall for the year 1902 may be taken as typical of the rainfall generally. During that year the total rainfall, as recorded at the Helena weir, amounted to 27½ inches, the total number of rainy days being 81; *i.e.*, the average precipitation per rainy day was only 0·34 inch. The maximum rainfall in any one day was 1·41 inch.

The unusual variations in the yield are due, in the Author's opinion, to two other causes, whose effects in new countries where records are scanty require much experience and consideration for their correct estimation. The first is that the rainfalls of York and Mundaring, which are all that are available, require to be greatly discounted, owing to a rapid rise of the country for several miles inland from Mundaring, and then a fall to the tableland of the interior; and it is therefore probable that the rainfall on the

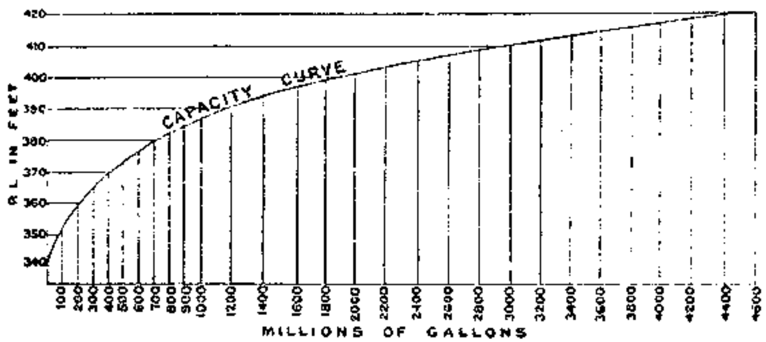
reverse slope of the Darling Ranges, and on much of the tableland adjoining, is less even than that at York. The second cause is that on the tableland, where the rainfall is smaller and the country is more absorptive than on the ranges, a large and more or less definite amount should be deducted from the rainfall before any estimate of the off-flow can be made. This opinion is supported by Tables I. and II. in the Appendix (p. 50). Table I. contains the results of gaugings at two points lower down the same river as that on which the reservoir is situated, with, for the sake of contrast, the results obtained from the catchment of a selected portion of the inland country which is adjacent to that which drains into the Helena. It also gives the results of gauging the Canning River at a spot where, although the catchment includes a larger proportion of quick-shedding ground than in the case of the Helena at Mundaring, the result, by no means apparent at first, is that the average yield of the total catchment is better than that of the Helena, although only half the size. Moreover, after the exceedingly low yield of 1902, the Author had weirs constructed across the several streams entering the reservoir-basin, and the results of gaugings are given in Table II. These results show conclusively the great conservative care necessary in dealing with questions of this kind in countries so dry as are parts of Australia, and they also justify the abnormal storage provided in the present case.

It was early evident that much of this difficulty would be obviated by placing the weir lower down the river (Figs. 2, Plate 1), and thus including a larger proportion of quick-shedding catchment. This, however, would have given a worse reservoir-site (*i.e.*, less impounding-capacity for the same expenditure), and would have entailed extra expense, both capital and annual, on account of the greater pumping-lift; the site higher up-stream was therefore adhered to. The startling results of 1902, however, could not be foreseen; and as, in the Author's opinion, the available records of rainfall (Table III., p. 51) render it more than doubtful whether, when the full estimated daily consumption is reached, even the 2 years' storage-capacity will be sufficient to tide over bad seasons, the responsibility was incurred by him of recommending any necessary additions to the works. It was not considered advisable to raise the reservoir-wall —although it is strong enough to bear some additional static pressure —since the diagram of capacities (*Fig. 5*) shows that the limit of economy of the site has already been reached; and it has therefore been recommended that so soon as the demand warrants that course, catch-water drains should be extended into the well-watered and

quick-shedding country draining into the Helena below the present weir. By this means, for an expenditure of about £45,000 (only 1½ per cent. of the total cost of the scheme), enough extra catchment-area could be included to ensure a yield from the present reservoir of 6½ million gallons daily—say 50 per cent. more than what is now a certainty.

Evaporation and Loss from Reservoir.—As will be explained later, the site of the weir was so badly fissured, and the basin of the reservoir so extensively crossed by basaltic dykes, that competent geological authorities believed that extensive stopping with concrete might be necessary. It was a matter of great interest, therefore, to ascertain what loss, if any, from the reservoir might result from this fractured condition; for it was decided that, except as regards the fissure across the site of the dam, no precau-

Fig. 5.



tionary measures should be taken in the first instance. Between the 1st November, 1901, and the 28th February, 1902, no water at all was drawn, and a favourable opportunity for testing the probable annual loss was thus afforded. The results are shown in Table IV. of the Appendix, and, as the total loss is at the rate of only 4½ feet of depth per annum—which is not much more than the evaporation alone should amount to—the danger of building where similar basalt dykes occur can be seen to be not excessive. The point is one of the greatest interest in Western Australia, not only because the location generally of the streams in the ranges seems to have been determined by the greater ease with which these basaltic dykes have been disintegrated and eroded, but also because practically the only site available for the reservoir of the ultimate gravitation scheme for the West Australian metropolitan area, lately

reported on by the Author, is even more fissured than that at Mundaring.

Quality of the Water.—Except in a few tracts where salts have been leached out of the soil by heavy rainfall, even the surface waters of Western Australia generally, although soft, contain a comparatively large amount of dissolved mineral matter, chiefly common salt. High chlorine results have therefore to be expected on analysis, and this test of possible contamination of the sources of supply, whatever its value elsewhere, is inapplicable; but as the catchment is so large, and as much of the area was alienated before the scheme was inaugurated, and would cost an excessive sum to buy back, a small amount of habitation on the catchment is inevitable. Moreover, except in these small patches, the land is covered with forest and scrub; and, with a small ratio of off-flow, the decaying vegetable matter would be expected to result in high ammonia figures on analysis of the water. Although this would in itself be harmless, it was recognized that the presence of the dissolved organic matter might be accompanied, on occasion, by dangerous bacteria of decomposition; and, as filtering before delivery is not included in the scheme, it was determined to institute periodical analyses in the first instance, and, later on, to make also regular bacterial examinations. The results of analyses made in February, May, October, and December, 1903, are given in Tables V.–VIII. of the Appendix, and disclose the fact that, owing apparently to anaerobic action in the pipes between the storage-reservoir and Coolgardie there is a marked improvement in the quality of the water.

Disposal of Surplus Flood-Waters.—Although when the scheme was inaugurated there were no gaugings by which the probable total inflow into the reservoir from year to year could be arrived at with certainty, there was ample evidence to show that the Helena and other streams similarly situated were liable to heavy floods; and as at the site chosen for the weir the valley through which the Helena runs converges abruptly, being in fact a deep gorge flanked on both sides by high hills, the width at the bed of the river being only 15 feet, and at 100 feet above the bed 750 feet only from solid rock to solid rock, the usual method of disposing of flood-waters, namely, by means of a by-wash, was precluded by its cost. It was therefore decided to pass all floods over the weir-crest, notwithstanding that calculation showed that for safety as much as 5 feet in depth over the whole length of the weir would have to be allowed for. Although, so far as the Author is aware, the weir is the highest overflow-weir in existence, this depth was

not considered excessive, because no debris whatever is brought down in floods, which, even when of the heaviest, could not be of very long duration. Indeed, the whole flow of the river lasts less than half the year at most, so that sufficient time is afforded for repairing any damage done to the weir-face and footings. In order to facilitate the descent of the water, the profile of the weir-crest was approximated to a parabola, and the form of the curve follows very closely that of the Holyoke Dam, in the United States, which was determined by experiment. The reservoir overflowed for the first time during the rainy season of 1903, and, for about 2 weeks, 6 inches of water flowed over the crest without doing any damage to the wall.[1] The water clung perfectly to the whole wall-face while descending. The same result is not to be expected when the depth over the crest is much greater; but obviously some departure of the deeper flowing water from the wall would not matter much. The downstream face of the dam is broken by three guide-walls which prevent any scour at its foot by the spill-water, which would otherwise have run along the toe; and where the wall is highest, a spill-water basin or water-cushion has been provided, from which a wide channel, excavated in the river-bed and lined with stone, carries all flood-water rapidly away clear of the dam and of the pumping-station below it.

The loss by evaporation and percolation has proved to be very small, and the overflow and draw-off arrangements of the reservoir have worked most satisfactorily.

II.—Construction of the Weir.

The weir was built to the section shown in Figs. 6, Plate 1, the governing factors of the design being that the maximum pressure on any portion of the wall should not exceed 8 tons per square foot, and that the centres of pressure should be well within the middle third, both with the reservoir empty and when 5 feet of water was flowing over the crest.

Preliminary Works.—The reservoir and the first pumping-station are situated at the bottom of a deep valley some miles from the nearest railway, and as all material, except stone for the concrete of which the weir was built, had to be brought from a distance, the first work put in hand was the construction of a tram-line, to the standard railway-gauge of the State, starting from Mundaring

[1] The Author has heard since the above was written that 1 foot 6 inches in depth of water passed over the crest in the beginning of August, 1904.

station on the existing line of railway. The next question was the provision, at a comparatively waterless spot, of a permanent supply of water fit for the use of the many men to be employed, as well as for the works. The requirements were met by constructing, in the bed of the future reservoir and about 9 chains above the weir-wall, a temporary concrete dam impounding about 20 million gallons, and by forming, from the by-wash with which this small reservoir was provided, a channel capable of carrying away 100 million gallons per diem. The channel was formed for the most part of open cut, but a timber flume carried the flood-waters across the weir-site.

Foundations.—Generally speaking, the country at the reservoir site is very rocky, consisting largely of undecomposed granite, traversed by intrusive basaltic dykes whose direction is mostly at right-angles to the course of the river. At the site of the weir, however, the granite showed out particularly clearly, and the few trial-shafts, put down where the rock was shattered, reached solid granite at no great depth, the deepest of the shafts being only 20 feet deep from the ground-surface. On opening up the foundations, however, it was discovered that the rock was nothing like as solid as surface indications and trial-pits promised; for on the right bank a large portion of what at first appeared to be bed-rock was found to consist of an immense boulder with a large cavity below it; and under the bed of the river the granite was very badly fissured over the full width of the foundations. It was not possible to vary the site, as the disruption was found to extend both up- and down-stream for a considerable distance; and there was no alternative but to follow the fissure down, which was done until a depth of 90 feet below river-bed was reached. At this level the filling material in the fissure was found to be so compact that it was but slightly eroded by a jet of water discharged under a pressure of 250 lbs. per square inch. It having been seen that the fissure had a northern underlay, a vertical boring was now made on the north bank of the river, which cut the fissure at about 165 feet below river-bed, and was continued for a further depth of 52 feet. The bore was then filled with water, and the material in the fault was subjected to a hydrostatic pressure equivalent to a head of 690 feet, which was maintained for 4 hours, during which time the foot- and hanging walls of the fissure, and the line of fissure at the bottom of the excavations, were all carefully examined; but no signs of moisture could be detected. It was concluded that the material in the fissure, at the depth which the excavations had then attained, was

impervious to water, and that it would therefore be safe to erect the weir thereon.

Where the wall would be highest, that is, where the fissure occurred in the foundations, the excavations were carried down about 15 feet from the building-line in a vertical direction on the up-stream face; but as one of the basaltic dykes crosses the valley a short distance away on the down-stream side, it was considered necessary to remove the whole of the material between the hanging wall of the dyke and what would otherwise have been the toe of the weir. The concrete filling of foundations was carried up to bed-level on the up-stream face, but on the lower side the mass filling was stopped 18 feet below bed-level and the wall proper was begun to the designed section. The granite beds, or floors, were deeply chased in longitudinal rows about 6 feet wide and 3 feet deep, and the toe of the wall-batter, where it met the granite floor, was channelled the whole length to key the concrete in.

The great inequality in the depth of the foundations, and their apparent doubtfulness for a work of this magnitude, have not appreciably affected the weir; for although very fine vertical lines, such as invariably occur in the concrete lining of service-reservoirs in hot countries, have made their appearance here, they have not extended, and any slight sweats have taken up.

Drawing-off and Scouring Arrangements.—The reservoir is provided with two valve-towers constructed of concrete. The inner tower (Fig. 7, Plate 1), situated on the reservoir side of the weir, was built into, and concurrently with, the main wall, being approximately semi-circular in section. The outer valve-tower (Figs. 8 and 9, Plate 2) is rectangular in section, and is situated 175 feet down-stream from the centre of the weir-wall, being connected therewith by a viaduct, which carries the outlet- and scour-pipes, all solidly bedded in concrete, as far out as the outer valve-house. Ingress to the inner valve-tower is obtained by means of a steel gangway running over the crest of the weir, and supported thereon by granite cut-water piers 52 feet apart between centres.

Provision is made for drawing water from the reservoir at three different levels, namely, at 25½ feet, 53 feet and 80 feet below full-supply level, by means of 24-inch cast-iron bell-mouthed pipes, passing through the valve-tower wall into a cast-iron stand-post. Each draw-off inlet is provided with a stop-valve placed in the valve-chamber, from which valve-rods are carried up to bevel-geared headstocks, all placed on the upper valve-tower floor, which is 1 foot 9 inches above maximum flood-water level of the reservoir.

Over each inlet are placed screens which can be removed for cleaning by means of chains worked by winches carried on an outer platform running round the valve-tower, and supported therefrom by brackets. Two 24-inch cast-iron spigot-and-faucet outlet-pipes pass from the stand-post, at 80 feet below full-supply level, through the weir-wall to the outer valve-tower. Each outlet is provided with a stop-valve in the inner valve-tower, and these are regulated similarly to the valves on the reservoir-inlets.

A 30-inch scour-pipe, leading from a fore-bay 90 feet below full-supply level, runs through the inner valve-tower, and through the weir-wall into the outer valve-tower. It is provided with a stop-valve in the inner tower, which is worked by a worm-geared head-stock placed on the upper floor. From the outer valve-tower the scour passes into the river, where it has its discharge. Both the outlet-pipes and the scour-pipe are provided with valves in the outer valve-tower, which will be brought into use only in the event of accidents to the regulating-valves in the inner valve-tower. Any water soaking through the wall of the inner valve-tower is led into a sump, whence it can be lifted into the scour-pipe by means of a water-ejector, supplied with pressure-water from the lowest inlet. At the outer valve-tower, the two 24-inch outlet-pipes junction into a 30-inch pipe, which runs to the stand-pipe in front of the engines at No. 1 station.

The details of all the ironwork used in the construction of the weir were drawn out in the State, and all ironwork was obtained from Great Britain. It speaks well both for the accuracy displayed in the preparation of the drawings, and for the care exercised in the manufacture of the various appliances, that when being grouped together as the work progressed, all parts fitted correctly into their respective places, without any alteration whatever.

The site of the reservoir, about 800 acres in extent, was grubbed and cleared, and all fallen timber and decaying vegetable matter was taken out of the river-bed and burned; later on the suckers and scrub were again cut down and burned. About 20,000 acres of the lower catchment-area was ring-barked with the object of increasing the inflow.

A concrete-lined spill-water basin, about 150 feet long by 100 feet wide, is constructed in the bed of the river, at the toe of the

wall, with a depth of water of about 10 feet. The water is confined by a mound across the river-bed constructed of rubble faced with concrete.

The excavations for the foundations were begun in May, 1898, and on their completion in January, 1900, the building of the wall was started, and was carried on both day and night until completion in June, 1902, an electric-lighting plant and eight arc-lamps placed at points of vantage affording ample light for operations by night.

Cement and Concrete.—In the construction of the weir-wall 76,418 casks of cement were used, and a further 1,090 in the spill-water basin and other subsidiary works, or a total of 77,508 casks, of which 19,767 casks were of German manufacture and the balance British. The German cement was chiefly used in filling the deep excavations made in sinking on the fault in the bed of the river.

The length of the average passage by steamer from London to Fremantle was more than 6 weeks, and by sailing vessel 90 to 100 days; and as on arrival in the State the cement was received into storage-sheds where it lay at least 1 month, but generally for a longer period, during which time tests were made preliminary to its despatch for use, the cement had some chance of losing any "freshness" which it might have had when first placed in casks, and needed comparatively little slaking. A cement which did not demand much slaking before use was especially necessary in connection with the smaller scattered works of the scheme, distributed as they were over 350 miles, and mostly in country whose dry atmosphere would not tend to satisfactory, or, at any rate, speedy, slaking. In these smaller works, the cement, having passed the necessary tests, was used direct from the casks, because to slake and then repack it would have entailed incommensurate expenditure; but at the weir provision was made for slaking fully all cement requiring it.

The tests, which were of an exhaustive character,[1] were directed not only towards determining the qualities of each batch of cement, but also to so ascertaining those qualities that after slight treatment in the State parcels which seemed at first to be doubtful might be used without hesitation. Situated, as the works were, at such a distance from the source of supply, this was essential. Taken altogether, the cements received were very satisfactory, and as the long-date tests become due, and the samples are examined and the briquettes broken, the results confirm the good qualities adjudged after the shorter tests. In all, ninety-two complete analyses were made, of which those in Table IX. (p. 54) may be accepted as average results. The specific gravity varied between 3·05 and 3·13. On the whole, the cement used was exceptionally well ground, that received towards the completion of the works being even finer than the earlier consignments. After the works were begun, a special set of bulk tests was carried out. Several casks of the different brands were sampled, and 25 lbs. of each brand was carefully passed through sieves with a mesh of 14,400 holes per square inch. The residues were—

German cement	7·04 per cent.
English cement	12·79 to 13·40 „ „

The tests of tensile strength ranged from the usual 3-day and 7-day hot- and cold-bath to 28-day cold-bath tests, a reserve of briquettes being often retained from the various batches for long-date tests. As a rule the results were very good, even when, fresh from the cask, the cement was subjected to the hot-water treatment. The hot bath was utilized to determine the necessity for slaking, it being found that a cement which showed a falling-off from the cold-bath results, when treated for a similar period in hot water, generally headed the cold-bath records after being fairly slaked: and there are numerous series of tests showing satisfactory increase in tensile strength at various dates up to 12 months. Cements, however, which showed a tendency to fall off in strength in hot water had to give undeniably good results after the requisite periods of slaking, before being despatched to the works.

One feature in the relative rise in temperature on hydration of slaked and unslaked cement is worthy of notice. On several occasions samples taken straight from the casks showed a comparatively small rise in temperature, yet the same cement, after exposure to the air, registered a considerable rise. For the purposes of closer examination a long series of experiments was made with the same shipment of cement air-slaked under three different conditions, namely:—

(1) Under the corrugated-iron roof of a shed.

(2) Under the wooden floor of the same building, spread in thin layers on a large tarpaulin and turned over daily; and

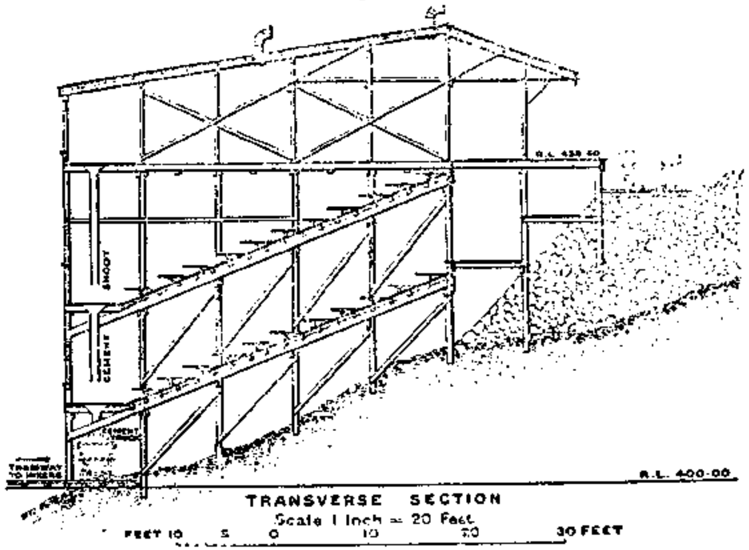
(3) Under the same floor, but placed in a box covered with wet

[1] In the year 1902 alone over 9,000 briquettes were made, not only for immediate use, but also to be broken for comparison, 3 months and 6 months and 1, 2, and 3 years after making.

bags, passages for currents of air being left between the cement and the bags, which were wetted and turned daily. The maximum rise in temperature is shown in Fig. 10, Plate 2. It is difficult to assign reasons for these results, but Table X. in the Appendix, obtained from long-date tests of this same consignment, shows satisfactory increase of strength.

The effect of slaking on subsequent expansion was also the subject of a long series of tests. Ordinary glass test-tubes, 6 inches by 1 inch, were filled with stiff grout, and placed in cold-water baths after the cement had set. The tubes usually cracked after 3 days or more when filled with fresh cement, showing a high rise of

Fig. 11.



temperature on hydration; but as slaking proceeded, so did the energy of the cement decrease. Further, there was apparently renewed activity after months of quiescence, tubes being cracked although the cement core itself remained hard and sound and, so far as the eye could detect, absolutely unharmed.

The receiving- and slaking-shed for the cement (*Fig. 11*) was built at the temporary end of the tram-line, that is, adjacent to its crossing of the weir-site, the upper floor of the shed being at the same level as that of the railway-wagons. The storage-capacity of the shed was 2,000 casks, and one-half of this quantity was taken by the slaking-tables, arranged on a falling gradient

so that one tipped on to the next and so on, until the cement arrived at a shoot leading on to the trucks, which conveyed it to the mixing-shed. A large portion of the cement, however, did not require special air-slaking. This, after having been put through a fine-meshed sieve, passed down a shoot to the concrete-mixer without being placed on the slaking-tables. Below the cement-shed, on the same level as the quarry-road, the stone-crushing plant was erected. It consisted of a No. 4 Gates crusher capable of dealing with 20 cubic yards of granite per hour, and driven by a 25-HP. Robey engine. In the same shed, but below the crusher, was situated the concrete-mixer, portable and self-contained, of the rotating-barrel type, mechanically fed with cement, stone and sand in the proper proportions, and capable of mixing 20 cubic yards of concrete per hour. All this machinery, from the cement-shed to the delivery end of the concrete-mixer barrel, was designed so that every operation which could be effected with advantage, or could be helped, by gravity, was so arranged; and the whole proved very satisfactory in working.

Except about 1,000 cubic yards of sharp, coarse-grained sand obtained from the river about 1 mile below the weir-site, the whole of the sand was brought from either Lion Mill or Bayswater, distant 8 miles and 22 miles respectively, by railway. That from the former was of quartz, and very fine-grained, yielding even and good results in the testing-room. The quarry, however, required heavy stripping of mould, and the sand itself required screening and thorough washing, to cleanse it from vegetable and earthy matters. This entailed the erection of a sand-washing plant. The sand from Bayswater was of a much better class, and required but light washing to free it from all earthy material.

About 30,000 cubic yards of spalls, for crushing to concrete size, were selected from the material obtained in the excavation of the foundations. For the plums and the balance of the spalls required, a quarry was opened on the north bank of the stream, below the weir, and about 70 feet above river-bed.

The weir and all accessories were built of concrete, but in the former, large rough granite blocks, just as quarried, were introduced into the concrete. It was originally intended to build the wall with 50 per cent. of these large blocks; but without proper plant, which was not available, handling would have been very expensive. The concrete consisted of 5 parts by measurement of granite crushed to 2½-inch gauge, 2 parts of cleaned sand and 1 part of Portland cement. So long as the wall remained below the

level of the mixing-house, the mixture was conveyed to the work on an endless conveyor working in a trough, with travelling boards secured by ropes and spaced 2 feet apart, thus ensuring that the heavier aggregate was not separated from the matrix on the way. Later, the concrete was conveyed on a trolley-line in skips, to a large derrick-crane, which lifted the skips on to temporary tram-lines on the growing wall: they were then pushed by hand to a travelling steam-crane which lifted each skip in a bridle, overturned, emptied, and returned it to its carriage. The concrete was spread and rammed by hand, the various layers being broken up so far as the width of wall would allow, in order to break bond in both beds and joints; and in addition, the large rough blocks, up to 2 cubic yards in volume, were deposited and thoroughly bedded and grouted, in order to key the bedding-planes together.

For the first 10 feet the batter was lined and the concrete retained by rubble masonry, but above this level wooden framing was substituted. This framing was of Oregon pine, and consisted of uprights 9 inches by 3 inches, and 15 feet long, cut to the sweep of the wall section, spaced 3 feet apart and closely lined on the wall face with 12-inch by ½-inch Oregon boards. For the first few feet upwards, the studs were held in position by shores, but later they were bored for 1-inch bolts about 18 inches long, at vertical intervals of 3 feet. Each bolt was fitted with an 8-inch by 3-inch by ¾-inch iron screwed washer-plate, which was built into the concrete, and remained there after the bolts were withdrawn and the holes grouted. Each vertical stud was lap-jointed and bolted to the succeeding one, the lap being sufficient to allow of two bolt-holds in the concrete before the lower boards were removed. No cross stays or ties were used across the wall, and the front and back framings were independent. The uprights were aligned throughout with a theodolite, the heads of each section being cut off to the required level and fixed to the width of wall corresponding with that level, with an allowance for outward pressure of the wet concrete. Rendering of the face was not desired or found necessary, as great care was taken, when depositing the wet concrete in contact with the moulding-boards, to keep all stone well back with straight spades, and a good finished face resulted on stripping. The valve-tower and viaduct, which were carried up with the main wall, were similarly built between moulding-boards, the frames inside and out being formed of upright studs, cross silled and lagged with 4-inch by 1½-inch tongued and grooved Oregon boards fixed vertically.

III.—The Pipe-Line.

The points on which the Commission of English engineers were asked to advise were, as regards pipes and main generally—

(*a*) "Whether the pipes should be laid in a trench and covered in, or left exposed to view."

(*b*) "Whether it would be safe to rivet up the whole line of pipes, or whether joints, to allow for contraction and expansion, are necessary; the kind of joint most suitable, should they be necessary."

(*c*) "Material and method of manufacture of pipes, whether welded or riveted, and whether welding and riveting shall be square or spiral." The use of cast iron being prohibited by the cost and the difficulty of freight both by sea and by land, the Commissioners were not to take it into account.

(*d*) "The diameter and thickness of pipes, and method of protecting."

As regards (*a*), the Commissioners were informed that there were possibly deleterious salts in the soil of a large part of the district through which the aqueduct would pass; and, for this reason, and also in order to avoid pressure on the empty pipes, to save the expense of trenching, and especially to facilitate detection and suppression of leakage, they recommended that the pipes should be laid above ground, uncovered, with expansion-joints.

The Commission recommended that the pipe should be of steel throughout, supported on bolsters, and riveted up in lengths of about 110 feet, with expansion-joints at these intervals, and anchor joints midway, fixed to masses of concrete or piles, in order to prevent the pipes from creeping. The minimum thickness was fixed at $\frac{3}{16}$ inch; and the pipes were to be longitudinally riveted where the pressure was such that the thickness of shell for riveted

Class of Pipe.	Number of Lengths of Pipe.					
	27½ feet long with plates ¼ inch thick and of internal diameter.			28 feet long with internal diameter 31 inches at larger end and reduced at smaller end according to thickness of plates to form telescopic joint.		
	26 Inches.	27½ Inches.	29 Inches.	Of $\frac{5}{16}$-Inch Plate.	Of ¼-Inch Plate.	Of $\frac{3}{16}$-Inch Plate.
Welded . .	5,592	4,393	5,710	..	..	..
Riveted . .	..	..	..	23,425	19,759	3,257

pipe was not required to be greater than ¼ inch, and welded for all higher pressures; with a minimum thickness of ¼ inch.

Tenders for the pipes were accordingly invited from Australia, Europe and America, the quantities specified for being as shown in the Table on p. 23. Tenderers were at the same time invited to submit alternative prices for any other kind of pipe which they desired to put forward. The lowest of the tenders received were as follows, the prices being for delivery in the Colony at a point 22 miles inland:—

Class of Pipe.	Lowest Tenders received in	
	Europe.	Australia.
	£	£
Riveted pipes	782,708	682,827
Welded "	472,600	..
Locking-bar pipes in lieu of welded pipes .	..	239,868
Total	1,255,308	922,695

The locking-bar pipe, for which alternative tenders were received, had been considered by the Commission and favourably commented on, but was not recommended for so large a scheme, because proof of its successful manufacture and use on any considerable scale was not then available. Subsequently, however, and before receipt of the tenders, 10 miles of main, 25½ inches in diameter, had been laid in South Australia. It had been found that pipes made from ¼-inch plate and fresh from the closing-machine would withstand a pressure of 400 lbs. per square inch—or nearly twice what would be allowed continuously in practice on pipes of this thickness of plate—without a weep; and, moreover, all pipes which did not stand the test could be passed back to the closing-machine to be reclosed, instead of being subjected to the usual caulking-processes so injurious generally to the plates and jointings. Practical use on a fair length of main also showed that the jointing could be successfully accomplished, thus leaving only questions of comparative cost and comparative usefulness to be considered in deciding whether the new pipe should or should not be used in place of welded and riveted pipes.

Taking first the Australian prices for locking-bar pipes and contrasting them with those for welded pipes, the saving is seen to be very marked, being within a few pounds of 50 per cent. Moreover, the price of locking-bar pipes was but little more than

that of riveted pipes. The lowest tenderers were therefore asked to consider the matter again, and they quoted prices for the locking-bar pipes which contrasted as follows with those received for the riveted pipes:—

Thickness of Metal in Pipe.	Riveted Pipe.	Locking-Bar Pipe.
Inch.	£ s. d.	£ s. d.
$\frac{3}{16}$	12 12 9	13 10 0
¼	16 5 0	16 15 0
$\frac{5}{16}$	20 3 6	21 0 0

Making a deduction of $\frac{1}{16}$ inch from the thickness of the plate to allow for corrosion and contingencies, and assuming a safe working-pressure of 7½ tons per square inch of net section of metal, the safe head of water on pipes of these thicknesses, and 30 inches in diameter, is shown by the following Table:—

Thickness of Metal in Pipe.	Safe Working-Head.	
	Riveted Pipe.	Welded Pipe.
Inch.	Feet.	Feet.
$\frac{3}{16}$	220	323
¼	340	485
$\frac{5}{16}$	458	647

The locking-bar pipe being as strong as welded pipe, it would be possible to effect considerable economy by using $\frac{3}{16}$-inch and ¼-inch locking-bar pipes, in place, respectively, of the ¼-inch and $\frac{5}{16}$-inch riveted pipes which had been specified originally; but it was recognized in the State, when pipes of so small a thickness as $\frac{3}{16}$ inch were included in those to be tendered for, that great care would be required in handling them, in order to prevent damage; and one result of the favourably low tenders was that a minimum thickness of ¼ inch was provided throughout, thus greatly increasing the probable life of the main in the very portions where the soil is worst, and the variations in temperature greatest. Moreover, by having one thickness and one diameter throughout, the contractors were induced to make a further reduction of 5*s.* per pipe, so that the whole length of main was laid with pipes 30 inches in diameter, thus effecting some saving in the capital cost of the pumps, as well as in the cost of pumping.

Summing up the position, the results of adopting locking-bar pipes and a uniform diameter throughout are these:—The section of the ground traversed by the pipe-line is such that, considered purely from the point of view of obtaining minimum pressures on the main throughout, it would be advisable to vary the diameters and thus use up superfluous head; but the variation of pressure with a uniform diameter could not be large if the pumping-stations were suitably located, and this slight disadvantage was considered to be more than counterbalanced by the reduction in the cost of the pipes and the other advantages attending a uniform, and to some extent larger, main. Moreover, the substitution of locking-bar for welded pipe, effected a saving of no less than 50 per cent. of the cost of the latter; and, although, as compared with the riveted pipes tendered for, the locking-bar pipes eventually provided cost $11\frac{1}{2}$ per cent. more, on the other hand, the latter were considered superior in several ways. Their frictional resistance, according to older accepted formulas, was less in the ratio of 2·5 : 3·1, a difference of 25 per cent.; and the probable damage in handling $\frac{1}{4}$-inch in lieu of $\frac{3}{16}$-inch plate pipes would be less, and the probable life of the pipes would be much longer: for the actual thickness required for safe working being about as 2 of locking-bar to 3 of riveted pipe the substitution of $\frac{1}{4}$-inch plate locking-bar pipe for $\frac{3}{16}$-inch riveted pipe meant a provision of $\frac{5}{24}$ inch of plate in place of $\frac{1}{16}$ for corrosion and damage; and the substitution of $\frac{1}{4}$-inch locking-bar pipe for $\frac{1}{4}$-inch riveted meant a provision of $\frac{7}{48}$ inch for corrosion in place of $\frac{1}{16}$ inch in the case of the riveted pipe, a difference, therefore, of 133 to 233 per cent.

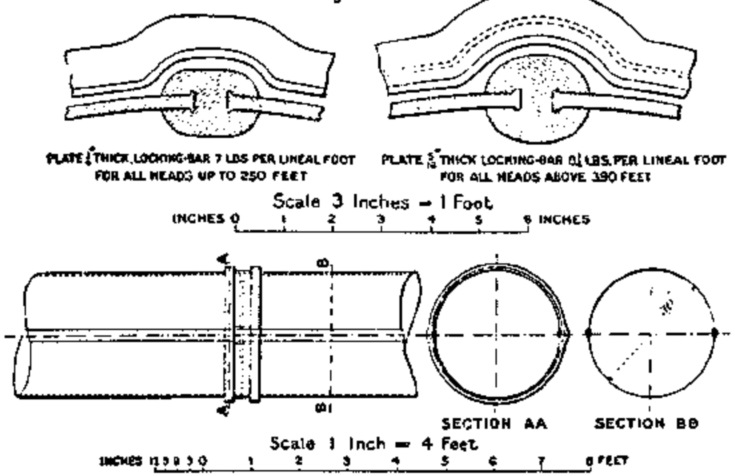
As the adoption of locking-bar pipes obviated the serious and continuous loss of water which was to be anticipated from a pipe having multitudinous rivet-holes, the question was considered whether the soils in which the pipe would have to be laid would tend to shorten its life, and if so, to what extent. As already mentioned, the natural water obtainable on the goldfields is highly mineralized; moreover, it often contains free acids. Therefore thin unprotected pipes in contact with this water could not have any lengthy life—a conclusion which experience has confirmed; but careful analysis of the soils along the pipe-track (Table XI.) showed that, where mining-operations did not entail distribution of such water on to the soil in which the pipes might be buried, this soil has been so much leached as to have lost many of its harmful properties, except, of course, in the salt-impregnated beds of the so-called "lakes." It was decided, therefore, that in the latter situation the pipes should be laid on trestles above ground, but covered with a low roof of galvanized iron; and that in the remainder of the section they should be buried, thus obviating any necessity for expansion-joints and permitting, in fact, the use of ordinary lead jointing.

The Coating.—In determining the composition of the coating to be used, wide extremes of temperature had to be allowed for. The fierce and continuous heat of the goldfields summer, when the temperature in the sun attains 150° to 170° F., is sufficient to render even block asphalt plastic. On the other hand, the frosts of winter would injuriously affect too hard a coating; and, moreover, as experiments showed, the extreme dryness of the soil at certain seasons, together with the heat, would very likely cause some loss of essential oils. As the result of a large number of tests of mixtures, made both at the pipe-works and at the head office, the coating used consisted of one part of asphalt and one part of coal-tar applied as described later, and freely sprinkled with sand while still hot and soft, to reduce the risk of the coating running when exposed in hot weather. No doubt the latter object could have been attained by more boiling, but the harder coating-mixture would have been brittle and more liable to flake off the pipes. Even the coating used ran to some extent when exposed for many days to the hot sun; but all exposure of metal, owing to this and other damage, was systematically made good just before the pipes were buried. The inside of the pipes was similarly coated—except, of course, that no sand was applied; but, as the water passing through is soft, although containing 20 grains of solids per gallon, and as vegetable acids are absent, much corrosion of the interior surface is not anticipated: and where the pipes have been emptied and opened 12 months after water started to pass continuously through them, the interior has appeared to be as clean and good as when they were first laid.

Joints.—A simple sleeve joint (*Figs. 12*) was adopted, the ring being 8 inches wide, and $\frac{1}{2}$ inch larger internally than the pipe externally, to allow for slight variations in the ring, and to permit of the use of lead filling throughout. For working-heads of 320 feet and less, the section of ring used was as shown in *Fig. 13*, the weight being 126 lbs.; but for heads of more than 320 feet a stronger form was used, as shown in *Fig. 14*, the weight per ring being 160 lbs. The finished jointing has proved very effective, the loss through leakage being small. From the pipes alone, on Sections 1–5, it was found to be 343 gallons per mile per diem. From the whole length of 295 miles between the storage-reservoir at Mundaring and the last pumping-station it was found to be 480 gallons

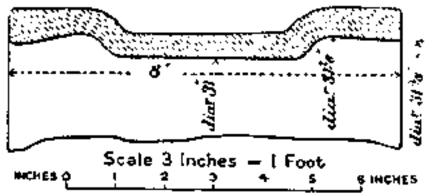
per mile per diem, over 10 months' working. This figure includes losses due to evaporation and percolation from nine pumping and

Figs. 12.



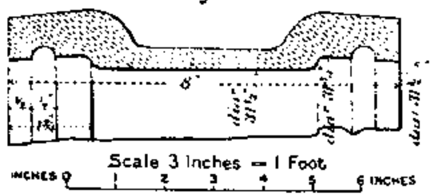
break-pressure reservoirs of contents aggregating 16½ million gallons.

Fig. 13.



As a direct line from the Helena reservoir to Coolgardie does not deviate far from the railway already built to the gold-

Fig. 14.



fields, it was resolved that from Northam eastward the pipes should be laid parallel with the railway and at a distance of

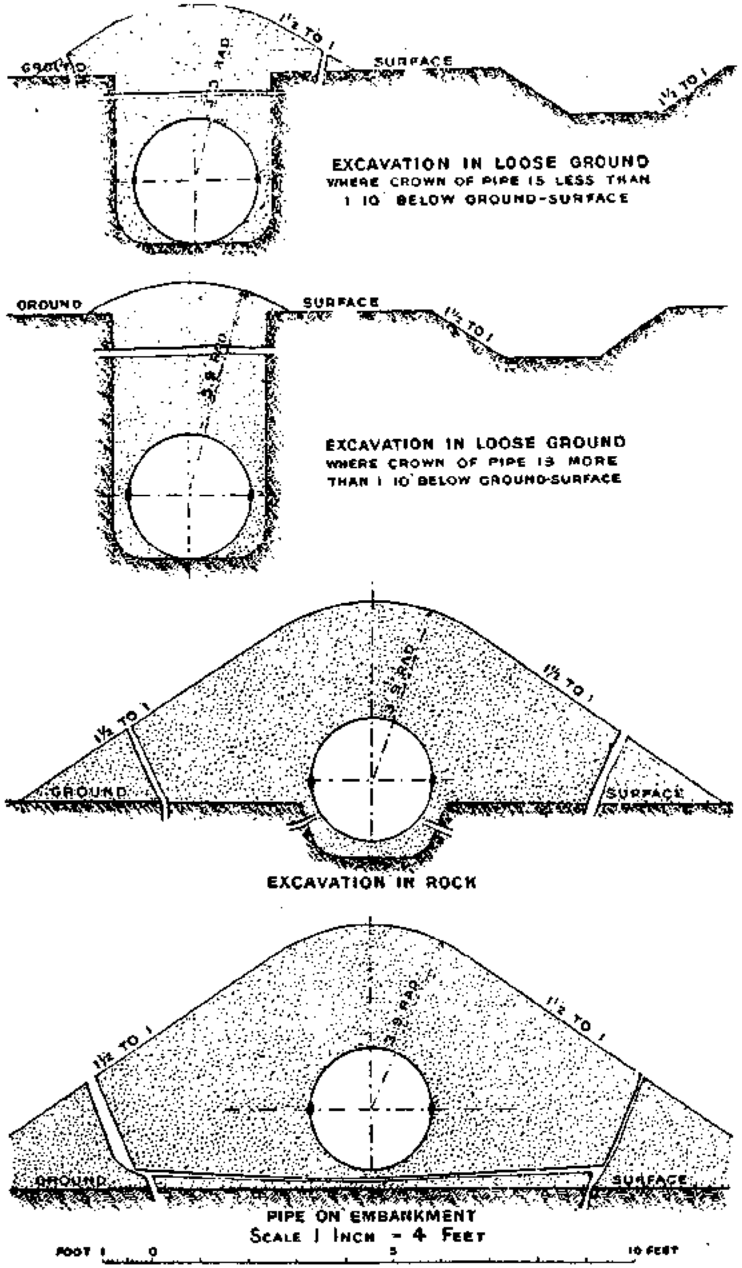
45 feet therefrom; thus gaining the great advantages of easy carriage and, subsequently, of easy supply of water to the railway: but between the weir and Northam the railway was deviated from, in order to shorten the distance, and also for the purpose of traversing higher country and thus reducing the pressure on the pipe.

Figs. 15 show the cross section of the pipe-trench and covering adopted. Where salt lakes or their beds occur, the main is carried on timber trestles, the pipes being surrounded by an insulation of saw-dust, which is kept in place by galvanized corrugated iron. This arrangement has been quite successful, no movements at the joints having taken place. Across the Avon River the pipe is duplicated, sunk beneath the bed of the river, and embedded in concrete. At railway- and road- crossings, the pipe is also protected by a shield of concrete.

At intervals of about 5 miles, stop-valves (*Figs. 16*) are inserted, the diameter of the main being reduced by cast-steel reducing-pieces to 21 inches. Where long rising gradients occur, reflux-valves are placed, the pipe being similarly reduced. Scour-valves are provided where required at both stop-valves and reflux-valves. The stop-valves are actuated by slow-motion gearing, and, on sections where the water-hammer was likely to be considerable, small by-passes were introduced, and so controlled that the water was brought to rest very slowly. Air-valves of the Glenfield pattern were placed at all summits, a nest of three being placed at the highest points, a nest of two at intermediate points, and a single valve at the lowest points. These valves are of the double type, provision being made for a large escape of air when charging the main, while air accumulating in the pipe is automatically discharged. This automatic discharge, instead of being obtained by varying the diameter of the ball, is effected by variation in the diameter of the orifice in the nipple. By this arrangement the nipple-orifices for the high points, where the pressure is light but where larger volumes of air accumulate, are of the largest diameter, and consequently afford the maximum provision for the discharge of air.

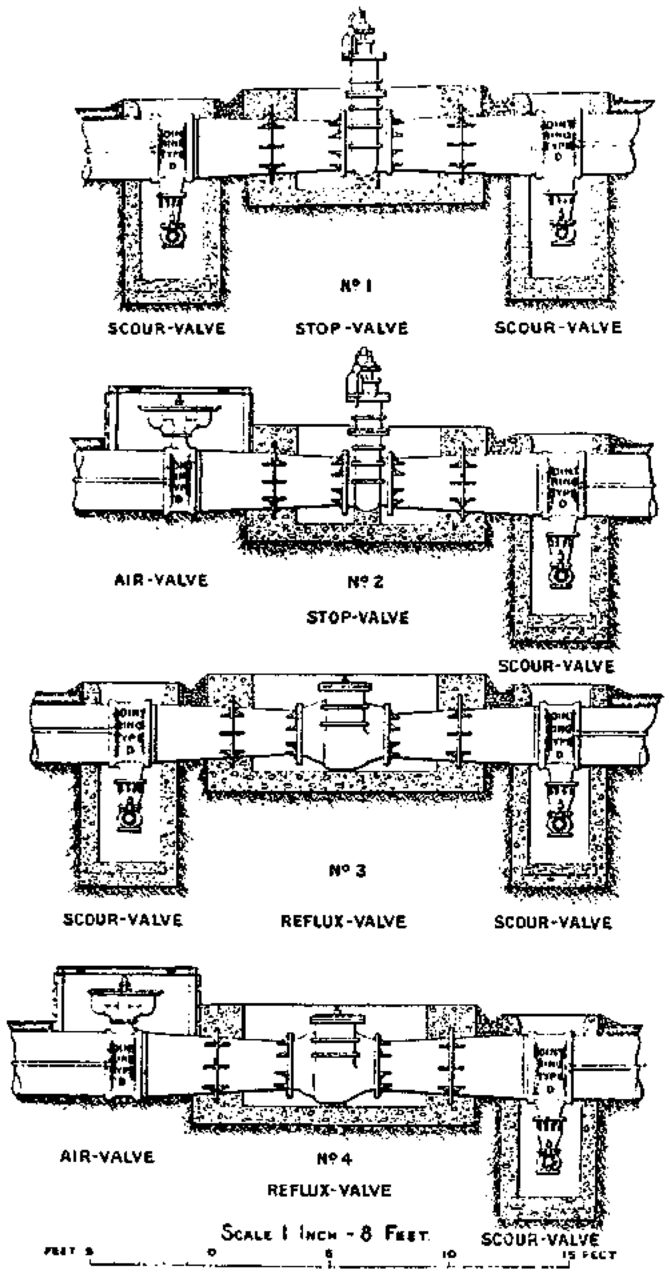
Manufacture of the Pipes.—Figs. 12 show the section of the pipe used, the dimensions varying according to the head. A pipe consists of two plates, each of the full length of the pipe and each bent to a semicircle. The edges are burred or beaded to the shape of a dovetail, and are inserted in the open jaws of heavy longitudinal bars, which are subsequently closed cold on to the edges of the plates, thus forming longitudinal dovetail joints. The steel used in both plates and bars was open-hearth basic steel with a specified tensile

Figs. 15.



Pipe in Cutting and in Embankment.

Figs. 16.



General Arrangements of Valves.

strength at first of not less than 25 tons, or more than 29 tons, per square inch. Experience gained in the manufacture of the pipes, however, showed that steel of this quality was somewhat too hard for the bars, which, owing to the cold working, failed under test by the bursting of the jaws before the plates were ruptured. It was also found that when bars weighing $6\frac{1}{2}$ lbs. and $7\frac{3}{4}$ lbs. per lineal foot were used, respectively, with $\frac{1}{4}$-inch and $\frac{5}{16}$-inch plates, the bars failed before developing the full strength of the plate; consequently, the respective weights of the bars were increased to 7 lbs. and $8\frac{1}{4}$ lbs. per lineal foot, the steel in the bars being of a tensile strength of between 22 tons and 26 tons per square inch. From each week's output of pipes at the works pieces were cut and tested to destruction. The results are given in Table XII.

The pipes were made in Western Australia from imported plates and bars. Of the former, one-half were brought from Germany, and the balance from America; but all the bars (and the joint-rings) were obtained from England. The plates, which were a trifle over 28 feet long by 4 feet wide, were first passed through horizontal rollers, three above and three below, for the purpose of taking out all kinks and rendering the plates perfectly straight. They were then cut square and to the exact length of 28 feet. The planing and dovetailing machine next cut them to the exact width, and then burred the edges by means of rollers to form the beading for the dovetail joint. The plates next passed through a longitudinal press wherein both edges were given the required curvature, thus avoiding any necessity for the beading or dovetail being passed between and damaged in the curving-rollers to which the plates were now brought, to be bent into semicircles in the usual way. On completion of this process most of the scale had been loosened and detached, and the plates, having been thoroughly cleansed of all remaining scale and rust, were ready to be formed into pipes. One semi-circular plate was now placed in a row of half circular cramps, resting on seats, and a locking-bar was fitted over each edge. Another semi-circular plate was then inverted and lowered until its edges rested in the upper grooves of the locking-bars. The upper halves of the cramps were then placed over the top of the pipe and connected to the bottom halves, and the plates were brought firmly home into the grooves of the locking-bars by tightening the cramps with cotter-pins. The pipe in its encircling cramps was then conveyed to a hydraulic closing-machine capable of developing a pressure of about 1,200 tons, wherein the locking-bars were pressed on to the plates, completing the manufacture of the pipe. The whole of the operations were performed without heating plates or bars.

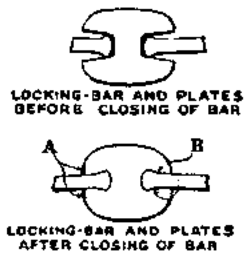
Each pipe, before being passed, was subjected to a hydraulic pressure of 400 lbs. per square inch. The closing of the locking-bars was so effectual that only a small percentage of the pipes were found to sweat at the bars. These were returned to the closing-machine and re-pressed, and this was found to stop the sweating effectually. About fifty pipes failed altogether in the joint under this test.

After being tested and passed, the pipes were coated. They were first heated to a temperature of 300° F. and then placed in a bath consisting of a solution of ordinary gas-tar and Trinidad asphalt, in the proportions already stated (p. 27), and kept at the boiling-point. On being lifted from the bath the pipes were allowed to drain for about a minute, and were then revolved in a machine while a jet of cold air was forced through them, for the purpose of ensuring that the coating should set in a uniform thickness. When it had cooled considerably, and just before setting, a sprinkling of sand was thrown over the outside of the pipe and gently pressed into the coating by means of rollers.

After all initial difficulties common to new methods of manufacture had been overcome, the pipes were turned out finished at the rate of 150 to 160 per diem from two factories, each of which worked two shifts of 8 hours each.

Two points required special attention in the construction and use of this pipe. The first was that the jaws of the locking-bar should be pressed well home on to the plates, no caulking of the joint being permitted at the manufactory. Unless this was very carefully done, water would enter at the ends and work along the pipe at B in *Figs. 17*, until some exit was reached. Examination of the pipe, and slight caulking at the ends before placing in trenches, disposed of such cases of opening of joints as were caused in a comparatively light pipe by handling and exposure after despatch from the manufactory. The second point also related to the necessity for closely pressing home the locking-bar, as caulking was not possible at the points marked A: the difficulty was overcome by cutting or chipping away the portions marked A.

Figs. 17.



Conveying, Distributing and Unloading Pipes.—The whole of the pipes had to be conveyed on the trucks of a single-line railway of 3-foot 6-inch gauge. Most of them were laid alongside this line, but those which had to be taken across country where the

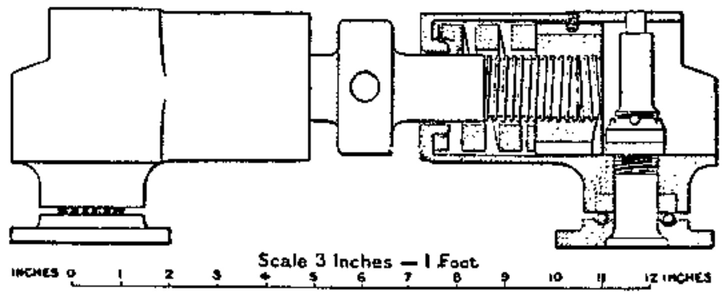
pipe-line deviated from the railway were conveyed from stations or sidings on specially constructed carriages. The pipes had to be distributed from the trains very quickly, so that the ordinary traffic on a fairly hard-worked railway would not be interfered with. The railway-wagons being each shorter than a pipe-length, two bogie-trucks were firmly coupled, thus giving a clear floor-length of 30 feet, and the pipes were placed thereon in three tiers. The bottom three pipes were kept in position on the trucks by means of chocks with removable gib-bolts, and three recessed bolsters, each placed across and over the bottom tier of pipes, carried the second layer, also of three pipes, which, in turn, were held in position by means of chocks and gib-bolts similar to those used for the bottom tier. In the recesses of the second layer of pipes a third tier of two pipes was placed. A truck-load therefore consisted of eight pipes, and the trucks were sent forward in trains of eleven to thirteen.

The unloading contingent of men, consisting of four gangs who, up to the arrival of the train, had been engaged on the excavation of the pipe-trench, then took charge. Each of these gangs consisted of six men, including a leading hand who controlled the gang's operations. Each gang had generally three trucks to unload, and when the train consisted of an odd number of trucks, the extra truck was allotted to the gang first getting to work. The average time occupied in unloading, from the time the loaded train left the siding until it returned thereto with the empties, was about 1 hour and 20 minutes, but the unloading was frequently done in less than 1 hour. During the remainder of the day the unloading gangs were kept at work on the excavation of the pipe-trench, sections of which had been left for this purpose. This system worked admirably, there being considerable rivalry between the various unloading gangs, and the general railway-traffic was not interrupted.

Joints.—As the whole length of main is of uniform diameter, the possibility of using machinery in place of hand-caulking of the lead joint was considered at an early stage. Careful trial at headquarters of joints caulked by hand and by a machine devised by a local firm, demonstrated that, whereas the machine-made joints when subjected to hydraulic pressure attaining 400 lbs. per square inch remained quite water-tight, on the other hand, slight sweats and pin-squirts manifested themselves in the hand-made trial joints submitted to the same test. As a 30-inch pipe of ¼-inch plate springs somewhat, even under the impact of a very light blow from the caulking-hammer, it is somewhat difficult to get hand-caulkers to finish a joint water-tight; moreover, in practice, men working in constrained positions for long hours, in manholes under the pipe-joints, cannot be expected to do uniformly good work. On the other hand, the machine caulking can be done by pressure applied uniformly on both sides of the joint-ring, and quite as uniformly on the lower as on the upper side of the pipe. Machine caulking was therefore decided on, with the good results in freedom from leakage already stated.

The caulking-machinery consisted of a portable oil-engine of the spontaneous-ignition type, built in Australia, and of about 5½ B.HP. The underframe of the engine also carried a dynamo which was belt-driven off the engine fly-wheel. The current was transmitted through a cable ¼ mile in length, so that about ½ mile of pipe could be caulked before moving the generating-plant to a fresh position. The cable was coiled on a drum carried on the after

Fig. 20.



part of the transport also carrying the caulking-machine, and a plug contact was used for connecting cable and motor, so as to permit of unhampered coiling and uncoiling of the cable on the drum. The caulking-machine (Figs. 18 and 19, Plate 2) was in two halves, one fitting over and the other under the joints of the main, and on the top half of the outer frame was carried the electric motor (of 2 HP.) which was belt-connected to a shaft, and by means of intermediate gearing worked the rims holding the caulking-tools (*Fig. 20*). These rims or racks were guided by small, hardened steel rollers, grooved on the outer circumferences of the racks, but plain on the inner circumference. Into jaws on the racks were slipped the caulking-tools, two in each rack, one operating on the upper half of the joint and the other on the lower half, *i.e.*, on the underside of the pipe.

The caulking-machine was mounted on a transport on which it

was carried along the top of the pipe, from joint to joint, the lower half of the machine being slung on the transport side by side with the upper half. On arrival at a fresh joint the lower half was lifted off, placed over the joint, and slid round it to the underside; the upper half was then lowered, and the two halves were fastened together, racks were clipped and the tools placed in position, the plug-connection between drum and motor was made, and the machine was started, the caulking-tools working round the pipe backwards and forwards until the lead was pressed home. The number of semi-revolutions found necessary ranged from five, where the caulking-rollers were $\frac{1}{4}$ inch thick, to seven, where $\frac{5}{16}$-inch or $\frac{3}{8}$-inch rollers had to be used to meet the varying distance between the inner surface of the joint-ring and the outer surface of the pipe. On completion of the caulking these tools were replaced by knives, which cut off the fillet in the last semi-revolution, bringing the racks back to their original position, and thus permitting the machine to be dismantled and moved to the next joint. When once fairly started, the operations were carried on without hitches, and the machinery of all descriptions, including motors and dynamos, worked well, notwithstanding that it was usually working in a cloud of dust due to the proximity of the trench-filling operations.

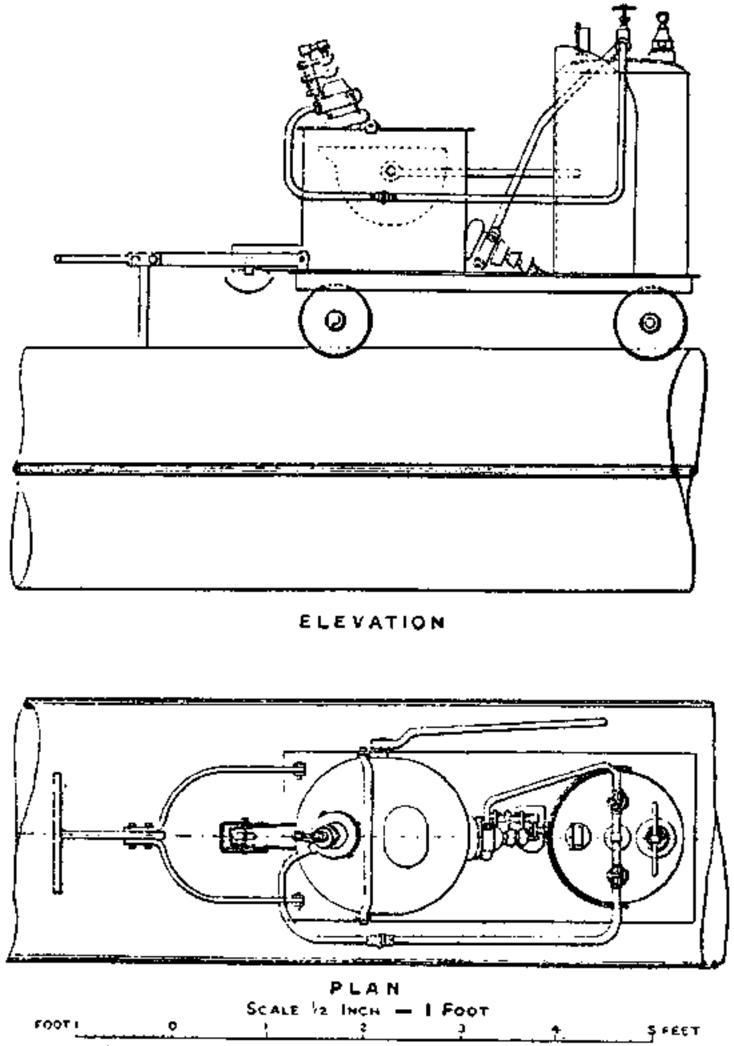
Each installation required three men (one a mechanic) for the working and transport of the caulking-machine, one man for the engine and dynamo, and two hand-caulkers, whose special function was to caulk at the locking-bars, whose projections prevented the rollers from working right round the pipe. In addition there were charges for parts of the time of mechanics and others whose duty it was to keep the electrical and other machinery in repair. The whole immediate cost of an installation per diem amounted to £5 1*s.* 4*d.*; and as the average day's work when the initial difficulties had been overcome was thirty-one joints, the cost per joint was 3*s.* 3*d.*, or 1*s.* less than hand-caulked joints were actually costing. In addition, the saving in the average size of manhole necessary was $1\frac{3}{4}$ cubic yards; and these two savings counterbalanced the whole cost, including the patent-rights of the machinery. There is no doubt that, with the experience gained, machine-caulking could be rendered cheaper than hand-caulking, especially for a circular pipe without projections; but the object in this case was to obtain uniform and certain work, and this was attained without extra cost.

Excavation of the Trench.—The surface formation of the country traversed is very irregular. On the plains, ironstone conglomerate predominates, but never extends continuously for more than a few chains at a stretch, being broken by bands of sand, diorite, and granite. In the timbered belts, sandy clay is the usual surface soil, but with outcrops of granite, diorite, and schist interspersed. Where at all possible, the material to be taken out was loosened by means of ploughs, each drawn by four horses harnessed in single file in the line of trench, and working to any depth required; but the bulk of the trench was taken out by manual labour, and it was necessary to use explosives on more than one-fourth of the total material removed. Where the material could be moved without the use of explosives, it was found that the most economical depth of trench, with due regard to cost of obtaining cover-material, was about 3 feet 3 inches. Where the country was harder, the trench was taken out to a less depth, the principle kept in view being that the cost of the trench, added to the cost of cover, should be a minimum. Occasionally, the contour of the ground would not admit of economical grading in combination with proper alignment for the pipes, and, in such cases, cost was subordinated to the more important consideration of easy alignment of the main. The excavation of the trench was kept well ahead of pipe-distribution, laying and jointing, but in order to provide continuous work for the gangs on these latter operations, should any hitches occur in the arrival of materials, sections of trench were left unexcavated at intervals.

Laying and Jointing Pipes and Filling in Trenches.—The work was divided into sections of about 14 miles each, to be dealt with by one caulking-installation, and when the work was completed the whole gang went forward to the next available section. When the works were brought into full swing, seven such gangs were at work on several sections; and, the class of work performed by each being identical, there was considerable rivalry between the parties. Bad work, due to haste, was prevented, however, by the appointment of an inspector on each section, who reported directly to the head office and was responsible only for the quality and not for the cost of the work, thus placing these departmental operations on the same footing as those of a contractor. The rate of progress during the last 3 months, before approaching completion caused disbanding, was, per day of 8 working-hours of seven gangs, $1\frac{2}{3}$ mile of laying, jointing, and complete filling-in of trenches. The appliances in use by each gang consisted of two pipe-lowering trestles, four skids, one pipe-expander, one lead-melter (*Figs. 21*) and retainer, and the engine and caulking-plant. The lead-running gave great trouble until the lead-melter was

devised, after which honeycombing and other similar faults were prevented.

Figs. 21.



GENERAL ARRANGEMENT OF LEAD-MELTER.

The sequence of the various operations was carefully regulated. Foremost were the men repairing the coating in the parts damaged during unloading or transportation, or where it had

become defective owing to exposure for a considerable time to the intense summer heat; and in the same set were the pipe-scrapers and locking-bar chippers, who chipped or scraped off the coating at each end of a pipe for a distance of about 6 inches, to ensure good lead-running. Next came men cutting manholes, a little ahead of those laying the pipes in the trench, and following these came the ring-setters, who wedged up the joint-ring to such gauge as would give a lead joint of uniform thickness. In succession were the lead-runners, whose work was, when possible, kept at least forty or fifty joints ahead of the caulking-machine, especially in winter, as showery and cold weather affected the quality of the lead-running: thus stoppage in such weather, or defective work which had to be remedied, did not delay the caulking-operations. Following on were the hand-caulkers, who caulked the joint at the locking-bar and for a distance of about 4 inches on each side of it. The best results were obtained not by allowing the hand-caulking to finish abruptly, but by tapering up to the uncaulked portion; by this means the machine rollers were able to work by degrees well back on to the hand-caulked portion; with an abrupt finish of the hand-caulked portion, the machine rollers were liable to race and cause breakages. This racing could of course have been avoided by extra care on the men's part, but at expenditure of unnecessary time, to save which would have entailed the danger of the rollers not being brought far enough along, thus leaving the joint imperfectly caulked at the junction of hand and machine work. After the hand-caulkers came the machine, and as each joint was finished the joint-inspector examined it; pipes were covered to a depth of at least 12 inches as soon as the inspector had passed a joint and it had been tarred, so that the partial filling-in was only two or three joints at most behind the machine. The completion of the filling-in and the formation of the covering bank was always 400 yards or more behind the machine.

Charging the Main.—By the 13th April, 1902, the works were sufficiently far advanced to enable pumping to be commenced with one of the engines at No. 1 station. No trouble was experienced in getting the engines under way; in fact, practically no hitch whatever occurred at any of the eight pumping-stations, and after once starting at any station the machinery was in condition to be worked, and was worked, whenever desirable. By the 22nd April the water had reached the Cunderdin Reservoir, at mile 77. Four months now elapsed before the laying and jointing of the next section was completed, and it was not till the 22nd August, 1902, that the water reached the Merredin receiving-tank at mile

140. Some little trouble was experienced in charging this section, through the joints leaking, due mostly to the subsidence of the pipes laid across the bad ground in the bed of the Mortlock River and adjacent soft country. It was through leakage of some of the joints on this section that what may be described as "sand cuts" were first experienced. They were caused by the joint action of the escaping water and the falling sandy covering, playing together on a small portion of the outer surface of the pipe. This action is somewhat similar to that of the sand-blast, and, under favourable conditions, one of the thin pipes used could be cut through in 4 to 6 hours. Fortunately, only six cases of the kind have been experienced so far. If discovered early, the placing of an encircling band on the pipe (such bands were kept in readiness) met the difficulty; but if the plate of which the pipe was made had a hole entirely or nearly cut through, a length of the main had to be emptied and the damaged pipe was replaced. To guard against occurrences of this nature, the upper halves of the lead joints were subsequently kept uncovered for some little time in country of a sandy nature, and where the main is under a head of 300 feet or more. The water reached the Coolgardie service-reservoir, at mile 328, on the 22nd December, 1902, and, finally, the Kalgoorlie service-reservoir, on the 16th January, 1903, about 8 months after the charging of the main was started. The pumping was restricted to an amount sufficient to fill about 12 to 15 miles of main per day, and, at this rate of charging, no trouble from air-pocketing was experienced, it being found that the air-valves had sufficient discharging-capacity to pass the volume of displaced and escaping air. The whole or part of the main has now been conveying water for nearly 2½ years without a burst having resulted either in the main or in the valves or other specials: the only occasions on which it has been necessary to empty any portion of the main have been when the "sand cuts" have occurred.

IV.—The Pumping-Machinery.

Frictional Resistance of Pipes.—It was originally calculated that for a discharge of 5 million gallons per diem through 30-inch riveted pipes the frictional resistance per mile would be equivalent to a head of 4 feet, which was obtained by applying Kutter's formula with a coefficient of roughness of 0·015, a figure deduced from the measured frictional resistance of the 48-inch riveted pipe of the East Jersey (U.S.) Water Company. But the change to a much

smoother pipe allowed of a considerably reduced provision. The Commission of English engineers had proposed a frictional allowance of 2·5 feet per mile for welded pipe; but, in view of the class of water to be dealt with, this allowance was increased by 20 per cent.; and as it was further determined to increase the daily quantity to 5,600,000 gallons, the ultimate allowance was raised to 3·76 feet per mile. On completion of the works, two tests, each of 12 hours' duration, were made, one over 22 miles and the other over 12 miles of pipe, the results on reduction showing an average resistance equal to 2·25 feet per mile for a discharge of 5,000,000 gallons per diem, or 2·8 feet for 5,600,000 gallons. These results, being for clean pipes, are considerably less than the ultimate estimates; and this was foreseen, for reference to Fig. 4, Plate 1, shows that the main was laid to an even less fall than 2¼ feet per mile, in order to save unnecessary present pumping.

The total ultimate friction-head for the whole distance from the weir to the main service-reservoir at mile 307½ of the aqueduct, calculated at 3·76 feet per mile, amounts to 1,156 feet, and the natural lift to 1,290 feet; and the aggregate loss at seven pumping-stations for reservoir provision being 122 feet, the total head to be provided for is 2,568 feet: but elevated ground between pumping-stations Nos. 2 and 3 made it necessary to raise water 87 feet higher than if the slope had been gradual, thus making the total head to be pumped against 2,655 feet.

The great advisability of keeping the machinery to uniform size and pattern finally determined that the pumping-stations, eight in number, should provide for a total lift, including friction, of 2,700 feet—or 45 feet more than was absolutely necessary —namely, 450 feet at the first four stations, and 225 feet at the last four. The waste head thus amounts to a trifle less than 1¾ per cent. Moreover, in regard to the advisability of uniformity, it was further decided that the first four stations should be fitted with three groups of machinery, any two of which should be capable of performing the required work; and that the last four stations should similarly be fitted with two groups, each capable of lifting the full quantity per diem. The power necessary had thus to be the same in every group, namely, 265 effective HP., but to allow for deterioration and contingencies the pumping power contracted for was nearly 303½ HP., or about 14½ per cent. extra.

The requirements and provisions may be summed up thus:—

	HP.
Effective horse-power necessary	3,120
" " provided for work . . .	3,642
" " " as reserve . . .	2,426

Tenders for the necessary pumping-machinery were invited in April, 1899, makers being permitted to submit alternatives as in the case of the pipes. In the result a contract was entered into with Messrs. James Simpson and Co., in March, 1900, for twenty groups of machinery at an aggregate cost of £241,750, excluding spares, but including erection. A detailed description of the machinery is outside the scope of this Paper, which, however, would be incomplete without the following brief account, and results of tests.

Description of Machinery.—The pumping-plant consists throughout of almost identical sets, the only difference being that in the first four stations the pump-plungers are 15 inches in diameter, working against a specified head of 450 feet, while in the second four stations the diameter is 21 inches and the head 225 feet. The engines are horizontal, six-cylinder, high-duty, triple-expansion, surface-condensing engines of the Worthington duplex, direct-acting type, the diameters of the high-, intermediate- and low-pressure cylinders being respectively 16 inches, 25 inches and 46 inches, the normal stroke of the pump-plungers 36 inches, and the piston-speed 150 feet per minute. The pump-plungers are externally and centrally packed, and directly connected with the steam-pistons. The pump-valves are of stamped bronze. The steam-cylinders are jacketed throughout on heads and barrels with steam at boiler-pressure, and the steam is re-heated on its passage both from the high-pressure to the intermediate-pressure, and from the intermediate-pressure to the low-pressure cylinders. The re-heater tubes which draw their steam from the cylinder-jackets are placed low, thus being the means of drainage for both cylinders and jackets. The steam-distribution is controlled by Corliss valves, placed in the cylinder-heads, and the cut-off in all cylinders is adjustable by hand while the engines are running. From the air-pump the condensed steam passes through an exhaust heater placed in the exhaust steam-main to the condenser, and is delivered into an elevated feed-tank in place of the ordinary hot-well. From this tank the water gravitates to a Webster heater and oil-separator where it is further heated by admixture with the jacket-condensation and with the exhaust from the boiler feed-pump. From the heater the feed-water is pumped by a Worthington feed-pump through the economizer back to the boilers. Steam is supplied by a nest of Babcock-Wilcox water-tube boilers, each designed to supply the necessary quantity for one engine, and having eighty-one tubes 18 feet long and 4 inches in diameter, a single drum 23 feet 7 inches long and 4 feet in diameter, with a superheater placed between water-tubes and drum. A Green economizer is provided for each installation. The chimney-stacks are of steel, 5 feet in diameter; those at the first two stations are 130 feet high, at the third and fourth stations 100 feet, and at the last four stations 90 feet.

At six of the pumping-stations, reservoirs 15 to 20 feet deep have been provided adjacent to the machinery, to receive the discharge from the main and to furnish a store for the pumps to draw from; and in order to reduce suction lift and facilitate pumping, the centre line of the pump-plungers has been kept below the top of the reservoir by about 8 feet. At stations Nos. 1 and 3, however, special arrangements were necessary. At No. 1 the pumps, if connected directly with the main from the large storage-reservoir, would have been subjected to a head of about 100 feet when this reservoir was full; and at No. 3, where there is ¾ mile of main between the large reserve reservoir and the pumps, the latter might have suffered from an undesirable hammer. The difficulty was overcome at each place by the provision of a stand-pipe open above, from which, as from a reservoir, the pumps draw.

Figs. 22, Plate 3, show the general arrangement of the machinery at stations Nos. 1 to 4, and Figs. 23 at the remaining four. The stations are brick buildings with corrugated iron roofs. The engines and pumps rest on granite bed-stones supported by brick piers resting in turn on a concrete floor. The pump-ends are bolted down to the bed-stones, but the cylinder-ends are allowed to move freely on expansion-rollers. The greatest care was taken in the laying of the foundations, only the best available material being used; and so far there has not been the slightest perceptible movement in the foundations of any of the twenty groups of machinery. The lower floors of the engine-rooms are of concrete rendered with cement mortar, and the upper or working floors are of jarrah timber resting on steel joists. The floors of the boiler-rooms are of concrete.

Efficiency of the Machinery.—The tests provided for by the contract were three, namely, (*a*) for the duty of the whole machinery under present conditions, that is, head low owing to clean pipes and new boilers worked to full pressure; (*b*) for the duty of the engines and pumps with steam at full pressure but the pipes throttled to obtain ultimate estimated head; and (*c*) for the capacity of the pumps with the pipes throttled and the boilers worked at 25 lbs. per square inch below present full pressure. Tests of the machinery of 12 hours' duration, at two stations to be selected by the engineer, were provided for, and the duty stipulated for was

in test (*a*) 135 million foot-lbs. for 160 lbs. of local coal worth 10,000 B.Th.U. per pound, which was taken as the equivalent of 1 cwt. of Welsh coal; in test (*b*) 135 million foot-lbs. per million British thermal units supplied to the engines and not returned in ordinary working to the boilers; and for (*c*) the full discharge with the terminal effective pressure of the low-pressure cylinders not more than 6½ lbs. per square inch, revolutions not more than 25 per minute, and piston-speed not more than 150 feet per minute.

The stations chosen for testing were Nos. 2 and 8, two groups being picked in the former and one group in the latter. Three separate preparatory tests were made to ascertain the slip of the pumps, the results being 0·6 per cent. at station No. 2, and 0·2 per cent. at station No. 8; and the respective plunger-displacements per foot of travel were, after correction for slip, 7·3645 and 14·7215 gallons. The coal in use varied slightly in quality, the calorific value per pound assigned at station No. 2 being 9916·7 B.Th.U. and at station No. 8, 10,058 B.Th.U. The values assigned to the combustibles found in the ash-pit were 11·637 B.Th.U. and 11·142 B.Th.U.

The results of the tests were that in test (*a*) the duty per 1,600,000 B.Th.U., the assumed equivalent of 1 cwt. of Welsh coal, was 144·4 million foot-lbs. at station No. 2, and 148 million foot-lbs. at station No. 8. In test (*b*) the engine-duty was nearly 142 million foot-lbs. at station No. 2 and nearly 143 million foot-lbs. at station No. 8. In test (*c*) the capacity of pumps per diem was found to be 6,093,000 gallons at station No. 2, and 6,177,000 at station No. 8. In each case, therefore, the results attained were well over those contracted for.

V.—Pumping- and Service-Reservoirs, Reticulation, etc.

The reservoirs provided are intended for three different uses, namely, to act as receiving- and suction-tanks, to regulate flow in the main, and for service purposes. There are seven suction-tanks, namely, one at each pumping-station except the first, the pumps of which draw from the storage-reservoir at Mundaring. Of the seven, all but one are concrete-lined tanks, of which that shown in Fig. 24, Plate 3, is typical; the exception is the large 10-million-gallon reservoir at mile 77, which was built some years previously for railway purposes and was taken over, as it is large enough to furnish a substantial reserve in case of accidents to the main or other works in the preceding portion of the scheme. The regulating-tanks, two in number, are also concrete-lined and are much the same in design as, although smaller

than, the receiving- and suction-tanks. That at Baker's Hill, (mile 24), regulates the flow at what is (allowing for friction) the highest point on the long and irregular section between pumping-stations 2 and 3; and the tank at West Northam (mile 36) not only reduces the extreme possible pressure on the pipes in the Avon valley by 100 feet, but also permits of regulation of the flow in such manner as to keep the pressures at a minimum in regular working. The service-reservoirs are three in number, namely, one of 1 million gallons at Coolgardie, one of 2 million gallons at Kalgoorlie, and the large one at Bulla Bulling. The two smaller reservoirs are concrete-lined, and otherwise much the same as the receiving- and suction-tanks above mentioned, being also provided with by-passes so that in case of accident or necessary cleaning the working of the scheme need not be interrupted.

The main distributing-reservoir at Bulla Bulling (Figs. 25, Plate 3), which has a capacity of 12 million gallons, with an available depth of 20 feet, is rectangular in shape (Figs. 26 and 27), two of the sides having slopes of 1 to 1 for the full depth of the reservoir, while the other two sides are vertical for a water depth of 8 feet from the top and then slope to the bottom of the reservoir. The vertical portion or wall rests on a bench 6 feet wide, from the inner edge of which the sloping lining is carried down to the bottom of the reservoir. The material of the reservoir-basin consists of indurated clay, ironstone conglomerate, and bands of limestone, the whole being badly fissured and pervious to water, and liable to disintegration and to slides due to greasy backs. The Author's experience of concrete-lined reservoirs on the West Australian goldfields had been such as to show conclusively that concrete lining, even 2 feet thick, would crack when exposed to the sun; and, moreover, the cost of thick lining in a reservoir of this size would have been excessive. It was therefore determined to limit the thickness of lining to 12 inches and to provide joints in the concrete to take the inevitable movements due to expansion and contraction.

The concrete used in lining both floors and walls was composed of 5 parts of machine-broken granite, the stones being of a maximum size of 2 inches, 2½ parts of sand and 1 part cement; all measured by bulk. What is commonly considered the only good class of sand was not obtainable nearer than 40 miles from the work, and the cost of carriage would have been heavy; but only 1 mile away there was found a very fine sand containing 5 per cent. of clay, and 15 per cent. of very fine

powdery silica, easily movable on washing. The loam, combined

Fig. 26.

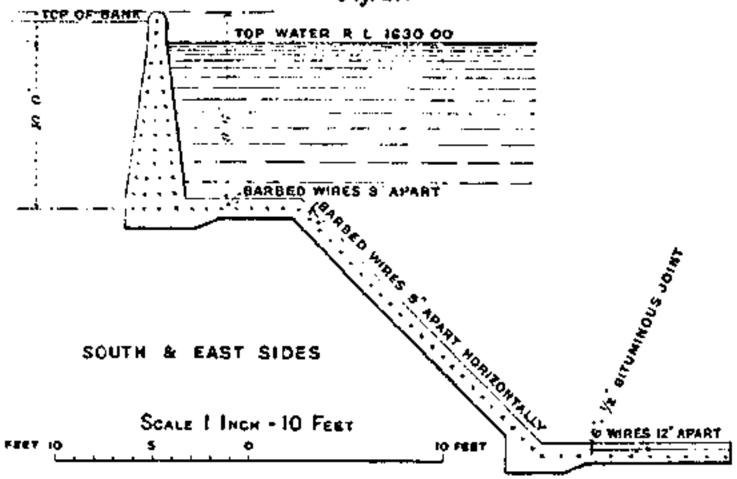
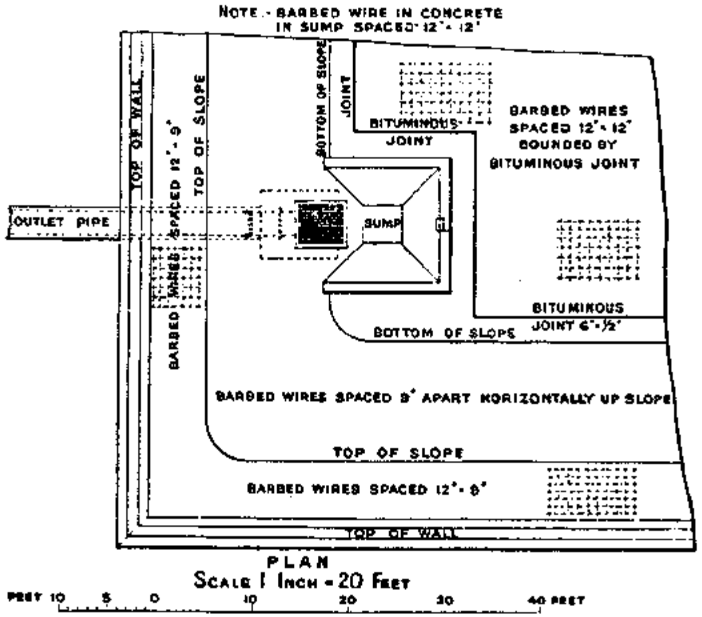


Fig. 27.



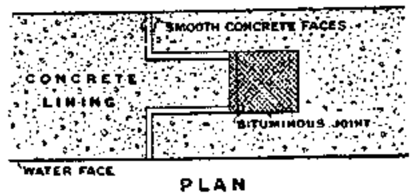
BULLA BULLING RESERVOIR: METHOD OF CONSTRUCTION.

with the extreme fineness of the sand (only 2 per cent. being

retained on a 250-mesh sieve, and 3½ per cent. on a 400-mesh), did not at first promise good results, but the mortar tests proved very satisfactory, and in fact the briquettes made with this sand (Table XII., p. 56) proved stronger than those made with the standard sand, which was clean, coarse, and sharp; the cement used for both sets of briquettes was taken from the same cask. It is generally considered that loam or clay is always injurious to cement mortars, but the results obtained in this instance throw doubt on the point, and confirm those obtained by Professor C. E. Sherman,[1] of the Ohio State University, which showed that in practically every case the substitution of loam and clay for a corresponding quantity of sand increased the strength of the mortar.

The floor of the reservoir, 12 inches thick, was put down in two layers, the first or bottom layer being 8 inches, and the top layer 4 inches thick. In the centre of the bottom layer, a grillage of barbed wire, spaced 12 inches apart, was put in, for the purpose of adding tenacity to the concrete, and thus giving it greater power to resist cracking under contraction. The upper surface of the bottom portion of the floor was purposely left smooth, so as to allow the upper layer to slide thereon. By this arrangement, the top portion acts as a false floor, and any temperature cracks are not so liable to continue into and through the bottom portion as would be the case with the floor built in one layer. At the junction of floor and sides a bituminous joint, 6 inches deep by ½ inch wide, is provided. The sides and walls are also reinforced with barbed wires running horizontally and placed 9 inches apart. The sides and walls were built in sections with a bituminous joint between each pair as indicated in *Fig. 28*. This arrangement effectually confined the results of contraction to the joints themselves, nearly every joint opening more or less at the faces, while the remainder of the lining remained intact. Soon after first filling, the reservoir, much of which was built in intense summer heat, was found to be leaking at the rate of 1¼ inch in vertical depth per diem; but

Fig. 28.



[1] "Effect of Clay and Loam on Cement Mortar." *Engineering News*, vol. l. (1903), p. 443.

instead of being spread in irregular cracks all over the reservoir, the leaks were confined to the lines on which the above-mentioned joints occurred: they were easily located, and were effectually stopped by cutting out portions of the joints to a depth of 2 or 3 inches, caulking with oakum, and facing with bitumen and tar.

Reticulation.—The original scheme did not allow for any reticulation of townships for domestic purposes, or of mining-centres, it being only intended to bring the water to some high hill —for instance, Mount Burgess a few miles north of Coolgardie —and to lay a subsidiary main thence to such situation in each township or mining-centre as the local authority should choose for its service-reservoir. Eventually, however, the complete reticulation of the townships of Kalgoorlie, Coolgardie, Boulder, and the Kalgoorlie Mining Belt, had to be undertaken as part of the main scheme, in addition to the laying of small pipes to mining-centres near Coolgardie and Kalgoorlie; but one or two of the smaller townships, namely, Northam and Southern Cross, have installed their own reticulation, purchasing water in bulk from the main scheme, and retailing it to the ratepayers.

A separate telephone-line for the works was laid down between the head office at Perth and Kalgoorlie. It is of ordinary type, with one repeating-station about half-way, and was extremely useful during construction. Connection is thus secured between the head office and the pumping-stations, and, by means of field-telephones, with the maintenance-gangers.

VI.—Cost of the Works.

The actual cost, including all extras, contingencies, and establishment charges, was £2,660,000, an excess of £225,000, or 9¼ per cent., on the original estimate, after deducting from the latter £65,000 for works which were allowed for therein but were not carried out. This can hardly be considered a large excess when it is remembered that the original estimate was based on tentative data prior to survey; but as a matter of fact almost the whole of the excess is accounted for by one item alone, namely, pumping-plant, partly due to somewhat more water having to be pumped, partly to the provision of more reserve power for accidents, and largely to enhanced cost per horse-power. Low-duty engines were originally allowed for at an estimated cost of £22 per horse-power, while the actual cost of the plant installed was nearly £48 per horse-power, including Federal customs duty, spares, etc. So

long as the consumption of water remains much below the ultimate amount allowed for, and so long as cheap local fuel (firewood) remains available, the high-duty plant will not prove as economical as the low-duty and cheaper plant would have been; but the conditions will be different when the full consumption is reached, and utilization of the more costly fuel becomes necessary.

The total expenditure of £2,660,000 was sub-divided as follows:—

	£
Storage-reservoir, including 5 miles of railway-line, land-compensation and river-training works (capacity of reservoir being 4,600 million gallons, the cost is £61 per million gallons of storage)	280,000
Service- and break-pressure reservoirs of a total capacity of 16 million gallons (£3¾ per 1,000 gallons)	60,000
Conduit 352 miles long, including all valves and specials (£5,312 per mile)	1,870,000
Pumping machinery, including erection, freight, Federal customs duty and spares (nearly £48 per horse-power)	290,000
Pumping-stations, exclusive of machinery but including the buildings, employees' quarters, suction-tanks, railway-sidings, coal-staithes and stores (£23 per horse-power)	140,000
Telephone-line and other contingencies	20,000
	£2,660,000

On the death of Mr. O'Connor, in March, 1902, the Author succeeded him as Chief Engineer, when about one-half of the works had been constructed. The progress was largely governed by the necessity for testing the long lengths of main between the various pumping-stations as soon as possible, and also by the rate at which the valves and specials could be obtained from England.

In conclusion the Author wishes to express his obligation to Mr. William Coates Reynoldson for much assistance rendered. Mr. Reynoldson was the Author's principal assistant on the scheme, and is now in charge of the works as Engineer to the Trust which was constituted by an act of the West Australian Parliament for maintenance and management of the works.

The Paper is accompanied by ninety-one sheets of drawings, from which the illustrations in Plates 1, 2 and 3, and in the text, have been prepared; also by an Appendix from which the following Tables have been selected for publication.

[Appendix.

APPENDIX.

Table I.—Discharges of Catchment-Basin of Helena River and of other Streams.

Year.	Helena River. Above Weir. Catchment 569 Square Miles.	Helena River. Between Weir and Station B. Catchment 50 Square Miles.	Helena River. Between Stations A and B. Catchment 10 Square Miles.	Canning River at Site of Proposed Reservoir. Catchment 282 Square Miles.	Spencer's Brook. Catchment 1½ Square Mile.
	Million Gallons.	Million Gallons.	Million Gallons.	Million Gallons.	Million Gallons.
1898	3,802	No record	No record	3,633	[2] 28½
1899	1,857	1,654	339	No record	19
1900	9,583	5,408	1,210	„	[2] 17½
1901	1,403	2,615	597	2,014	6¼
1902[1]	306	845	418	705	¾

[1] To end of October only.

[2] Reservoir overflowed 9 September, 1898, and 28 July, 1900, and the water that went to waste is *not* included in the above figures.

Table II.—Discharge of Streams entering Mundaring Reservoir 1 January, 1903, to 16 August, 1903.

Name of Streams.	Area of Catchment.	Total Catchment of Group of Quick- and Slow-shedding Catchments.	Discharge.	Total Discharge of each Group.
	Square Miles.	Square Miles.	Gallons.	Gallons.
Creek A	7·0	..	62,271,000	
Pickering Creek . . .	10·0	..	68,046,000	
Rushy Creek	18·2	35·2	166,277,000	246,594,000
Darkin River . . .	260·0	..	234,924,000	
Helena above junction of Darkin	270·0	530·0	275,755,000	510,679,000
Falling direct into reservoir and on balance of catchments	4·0	4·0	53,460,000	53,460,000

Table III.—Rainfall at Perth Gardens, Mundaring and York.

Year.	Perth Gardens.	Mundaring.	York.	Year.	Perth Gardens.	Mundaring.	York.
	Inches.	Inches.	Inches.		Inches.	Inches.	Inches.
1876	28·73	No record	No record	1889	39·96	No record	19·99
				1890	46·73	„	22·97
1877	20·48	„	13·90	1891	30·33	„	15·19
1878	39·72	„	19·80	1892	31·23	„	13·66
1879	41·34	„	12·50	1893	40·12	49·75	23·31
1880	31·79	„	18·57	1894	23·72	29·46	10·99
1881	24·78	„	14·85	1895	33·01	44·24	16·18
1882	35·68	„	19·48	1896	31·50	37·65	15·83
1883	39·65	„	23·96	1897	27·25	35·78	13·29
1884	31·96	„	19·17	1898	32·04	43·50	16·94
1885	33·44	„	22·19	1899	31·96	37·50	16·84
1886	28·90	„	14·18	1900	36·25	45·58	21·10
1887	37·52	„	16·79	1901	35·84	35·76	13·16
1888	27·83	„	13·66	[1] 1902	26·73	26 45	10·66

[1] To end of October.

Table IV.—Evaporation at Perth Observatory, and at Mundaring Reservoir.

July, 1901, to June, 1902.

1	2	3	4
Month.	Evaporation at Perth Observatory.	Fall of Water-Level Reservoir. Per Month.	Fall of Water-Level Reservoir. Per Day.
	Inches.	Inches.	Inches.
July, 1901	2·06	1·73	0·0558
August, 1901	1·75	1·47	0·0474
September, 1901	3·20	2·69	0·0896
October, 1901	5·51	4·62	0·1493
November, 1901	7·69	6·45	0·2150
December, 1901	9·47	7·95	0·2564
January, 1902	10·22	8·58	0·2767
February, 1902	8·35–35·73	7·01	0·2503
March, 1902	8·26	6·93	0·2235
April, 1902	5·21	4·37	0·1456
May, 1902	2·27	1·90	0·0613
June, 1902	1·80	1·51	0·0503
Totals and averages . .	65·79	55·21	..

Note.—The figures in column 2 were furnished by the Government Astronomer as being the loss per diem in Perth. The total of figures in column 3 for the 4 months from 1 November, 1901, to 28 February, 1902, was obtained by observation at Mundaring Weir as 2 feet 6 inches, and the figures for each month, shown in columns 3 and 4, were calculated therefrom at the proportion obtained from column 2.

TABLE V.—ANALYSES OF WATER, FEBRUARY, 1903.

Parts per 100,000.

——	Ammonia. Free.	Ammonia. Albuminoid.	Oxygen absorbed in 4 Hours.	Nitrogen as Nitrates.
Coolgardie Reservoir	0·008	0·0375	0·228	0·016
Mundaring Reservoir: foot of dam	0·014	0·06	0·171	0·0066
Mouth of No. 1 Creek, south side .	0·012	0·064	0·15	0·012
Centre of reservoir opposite No. 1 Creek	0·012	0·072	0·135	0·011
Centre of reservoir 1,000 yards above dam	0·01	0·086	0·121	0·0092

TABLE VI.—ANALYSES OF WATER, MAY, 1903.

Locality.	Parts per 100,000. Free Ammonia.	Parts per 100,000. Albuminoid Ammonia.	Parts per 100,000. Oxygen absorbed in 4 Hours.	Parts per 100,000. Nitrogen as Nitrates.	Grains per Gallon. Total Solids.	Grains per Gallon. Chlorine.	Hardness Degrees
*Helena Weir .	0·004	0·040	0·190	0·0145	27·49	9·94	7·0
No. 2 Tank .	0·006	0·040	0·184	0·0131	27·35	9·94	7·5
Baker's Hill .	0·012	0·026	0·171	0·0132	30·29	10·22	7·0
W. Northam .	0·012	0·026	0·148	0·0131	26·18	10·08	7·5
*Cunderdin Reservoir . .	0·014	0·025	0·166	0·0165	24·64	10·22	7·5
*No. 4 Tank .	0·012	0·026	0·129	0·0130	23·94	10·22	7·5
,, 5 ,, .	0·006	0·024	0·117	0·0198	24·39	10·36	8·0
* ,, 6 ,, .	0·010	0·024	0·113	0·0180	25·14	10·22	8·0
,, 7 ,, .	0·015	0·020	0·166	0·0264	25·99	19·36	8·0
* ,, 8 ,, .	0·008	0·016	0·138	0·0210	24·88	10·22	8·0
Bulla Bulling	0·012	0·020	0·144	0·0105	23·[illegible]4	10·22	8·0
*Coolgardie Reservoir . .	0·012	0·024	0·162	0·0158	23·27	10·22	8·0
*Kalgoorlie Reservoir . .	0·006	0·020	0·159	0·0165	22·96	10·36	8·0

TABLE VII.—ANALYSES OF WATER, OCTOBER, 1903.

Locality.	Parts per 100,000. Free Ammonia.	Parts per 100,000. Albuminoid Ammonia.	Parts per 100,000. Oxygen absorbed in 4 Hours.	Parts per 100,000. Nitrogen as Nitrates.	Grains per Gallon. Chlorine.	Hardness Degrees.
Mundaring Reservoir .	0·002	0·028	0·1	0·0085	10·5	6 5
No. 2 Receiving-tank .	0·001	0·03	0·1	0·0066	11·1	7·0
Baker's Hill Regulating-tank	0·006	0·03	0·09	0·008	13·9	8·0
West Northam Regulating-tank	0·008	0·028	0·7	0·009	14·0	8·0
Cunderdin Reservoir .	0·015	0·034	0·21	0·06	10·9	6·5
No. 4 Receiving-tank .	0·002	0·03	0·08	0·0066	13·6	7·5
No. 5 ,, ,, .	0·003	0·034	0·23	0·005	6·3	3·5
No. 6 ,, ,, .	0·01	0·034	0·16	0·011	10·3	6·0
No. 7 ,, ,, .	0·004	0·03	0·07	0·01	14·0	7·5
No. 8 ,, ,, .	0·002	0·036	0·26	0·033	6·4	3·5
Bulla Bulling Reservoir	0·002	0·032	0·21	0·0066	7·5	4·0
Coolgardie Reservoir .	0·015	0·014	0·307	0·006	5·5	3·0
Kalgoorlie Reservoir .	0·018	0·03	0·3	0·016	6 0	3·0

TABLE VIII.—ANALYSES OF WATER, DECEMBER, 1903.

Locality.	Parts per 100,000. Free Ammonia.	Parts per 100,000. Albuminoid Ammonia.	Parts per 100,000. Oxygen absorbed in 4 Hours.	Parts per 100,000. Nitrogen as Nitrates.	Grains per Gallon. Chlorine.	Hardness Degrees.
Mundaring Reservoir .	0·010	0·025	0·320	0·020	6·2	4·0
Helena River, near Byfields Weir, No. 5 .	0·003	0·009	0·176	0·007	28·41	10·0
Pickering Brook Weir, No. 2	0·003	0·008	0·032	0·0066	10·39	3·5
Rushy Creek Weir No. 3	0·008	0·017	0·104	0·004	24·95	8·0
Darkin River Weir, No. 4	0·004	0·011	0·224	0·004	7·62	3·5
Cunderdin Reservoir .	0·005	0·018	0·233	0·017	7·39	3·5
No. 6 Receiving tank .	0·010	0·0080	0·178	0·0017	6·20	6·0
Toorak Reservoir . .	0·008	0·025	0·167	0·02	7·62	3·5
Bulla Bulling Reservoir	0·009	0·024	0·207	0·21	7·62	3·5
Kalgoorlie Reservoir .	0·008	0·011	0·173	0·22	8·54	3·5

TABLE IX.—ANALYSES OF CEMENT.

Origin of Cement.	Composition of Cement.						
	Silica SiO_2.	Iron and Alumina Fe_2O_3 Al_2O_3.	Lime CaO.	Magnesia MgO.	Sulphuric Anhydride SO_3.	Carbonic Anhydride CO_2.	Moisture H_2O.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
German cement	23·61	9·21	64·27	0·94	0·96	0·41	0·48
,, ,,	23·90	9·50	63·62	0·90	1·15	0·38	0·36
English cement	25·11	11·39	60·81	0·84	0·76	0·60	0·34
,, ,,	25·23	11·97	60·17	1·02	1·15	0·40	0·22
,, ,,	24·30	12·10	61·32	0·94	0·81	0·51	0·22
,, ,,	24·14	11·04	61·44	0·83	0·83	0·45	0·24
,, ,,	24·11	12·01	61·10	0·99	0·98	0·46	0·30
,, ,,	23·71	11·61	62·05	0·87	1·14	0·52	0·39
,, ,,	23·05	13·35	60·02	0·68	1·56	0·40	0·23
,, ,,	24·11	12·50	61·20	1·00	0·90	0·37	0·22

TABLE X.—TESTS OF TENSILE STRENGTH OF CEMENT.

Number of Days Slaked.	Tensile Strength per Square Inch.									
	Neat Cement.						3 Sand and 1 Cement.			
	7 Days.		28 Days.	3 Months.	6 Months.	1 Year.	7 Days.	28 Days.	6 Months.	9 Months.
	Lbs. Cold.	Lbs. Hot.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
0	687	571	759	906	986	1,011	162	206		
6	688	792	783	..	..	..	177	207		
8	..	..	..	780	942	1,008				
9	..	..	800							
254 (a)	320	..	567	801	794	9 Months. 790	..	..	322	323
252 (b)	319	..	527	676	805	847				

(a) and (b).—The slaking was effected respectively under conditions (2) and (3) outlined in the Paper (p. 19).

TABLE XI.—ANALYSES OF SOILS ALONG ROUTE OF MAIN.

Sample Number.	Place.	Reaction.	Moisture.	Loss on Ignition = Total Organic Matter.	Total Soluble Matter.	Sodium Chloride NaCl.	Carbonic Anhydride CO_2.	Humic Acids.
			Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
			Made September, 1898.					
1	Hines Hill (surface) . . .	Alkaline	4·75	5 3	0·45	0·05	0·16	0·2
2	Hines Hill (3 feet below surface)	,,	13·86	15·205	0·25	0·37	0·29	0·1
3	Southern Cross (surface) . .	,,	10·36	8·9	0·212	0·14	3·85	0·56
4	Southern Cross (3 feet below surface) . .	,,	10·39	15·901	0·725	0·7	14·6	Nil.
5	Boorabbin (surface)	Acid (faint)	2·948	4·5	0·235	0·065	0·93	0·36
6	Boorabbin (3 feet below surface)	Acid (faint)	3·08	4·410	0·188	0·03	Nil.	0·04
7	Coolgardie (surface) . . .	Acid	1·58	6·97	0·24	0·04	0 12	0·16
8	Coolgardie (3 feet below surface) . . .	,,	2·248	6·47	0·06	0·03	0·15	0·16
9	Yellowdine (surface) . . .	,,	1·78	4·36	0·55	0·07	0·153	0·13
10	Yellowdine (3 feet below surface) . . .	Alkaline	8·62	3·77	1·9	0·04	2·05	0·038
			Made December, 1898.					
11	Yellowdine Salt Lake (surface)	,,	3·9	5·27	4·076	3·6	0·59	0·16
12	Yellowdine Salt Lake (3 feet below surface)	,,	3·82	5·024	4·97	4·3	0·169	0·12
13	W. Cunderdin Clay Pan (surface) . . .	,,	0·352	2·20	0·278	0·09	0·44	0·36
14	W. Cunderdin Clay Pan (3 feet below surface) . . .	,,	5·056	7·972	0·805	0·6	0·62	0·028
15	E. Cunderdin Sand Plain (surface) . .	,,	18·9	2·244	2·45	0·08	2·56	0·38
16	E. Cunderdin Sand Plain (3 feet below surface) . . .	,,	12·23	7·422	2·57	0·05	0·467	0·39

NOTE.—Moisture estimated on soils as received. Other estimations made on water-free samples.

TABLE XII.—TESTS OF SPECIMEN PIECES OF LOCKING-BAR PIPES.

Number of Pieces Tested.	Thickness of Metal in Pipe.	Weight of Locking-Bar per Lineal Foot.	Number of Pieces that Failed		Average Breaking-Stress of Plate of Pieces which Failed	
			In the Locking-Bar	In the Plate.	In the Locking-Bar.	In the Plate.
	Inches.	Lbs.			Tons per Sq. Inch.	Tons per Sq. Inch.
124	$\frac{1}{4}$	$6\frac{1}{2}$	90	34	19·3	26·0
130	$\frac{1}{4}$	7	47	83	22·6	26·3
3	$\frac{1}{4}$	$7\frac{3}{4}$	..	3	..	26·8
30	$\frac{5}{16}$	$8\frac{1}{4}$	9	21	23·8	25·7

TABLE XIII.—TESTS OF BRIQUETTES MADE FROM STANDARD SAND AND FROM SAND USED FOR BULLA BULLING RESERVOIR CONCRETE.

(3 Sand to 1 Cement).

—	Breaking-Stress per Square Inch.				
	7 Days.	28 Days.	3 Months.	6 Months.	1 Year.
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Sand, as used in reservoir, containing 5 per cent. loam	240	336	410	466	522
Clean standard sand . .	158	257	312	377	388

BOOKLET: FACSIMILE EDITION OF 'NORTH EASTERN GOLDFIELDS, FROM KOOKYNIE TO LAVERTON' - 1903

THE FACSIMILE EDITION OF
THE 'MORNING HERALD' SERIES OF
WEST AUSTRALIAN GUIDE BOOKS

NORTH EASTERN GOLDFIELDS

from KOOKYNIE to LAVERTON

There was a time when a host of small bush outposts to the north of Kalgoorlie rivalled even that town's fabled gold discoveries. The 'yellow fever' of the 1890s in the Eastern Goldfields gave birth to communities that today are mostly forgotten: Kookynie, Malcolm, Leonora, Anaconda, Murrin Murrin, Yundamindera, Mount Morgans, Laverton, Tampa . . . In this book, published in 1903, their memory is revived and the story told of the greatest engineering feat of the day – the Perth-Coolgardie water supply pipeline. It was a time of setting the scene for Western Australia's future progress.

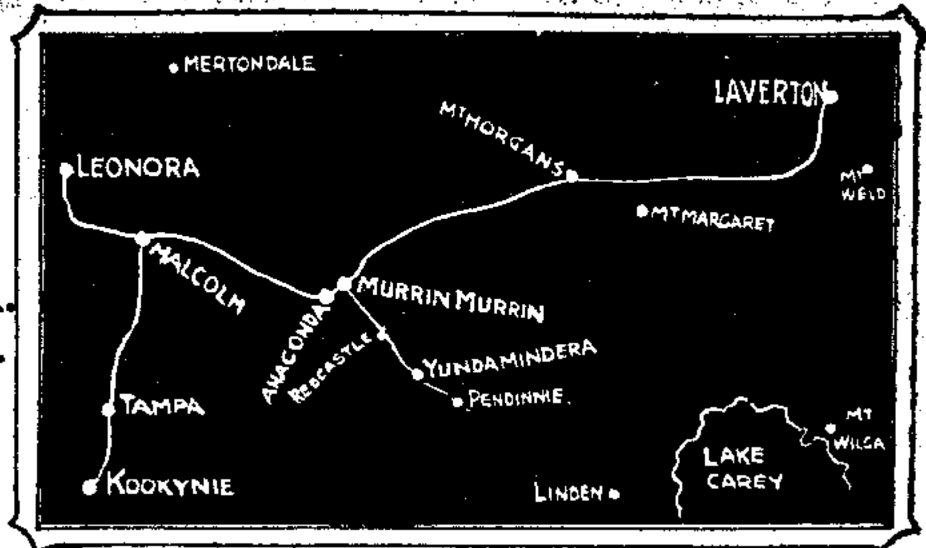
THE "MORNING HERALD" SERIES OF WEST AUSTRALIAN GUIDE BOOKS. No. 2.

NORTH EASTERN GOLDFIELDS.

PRICE 6D.

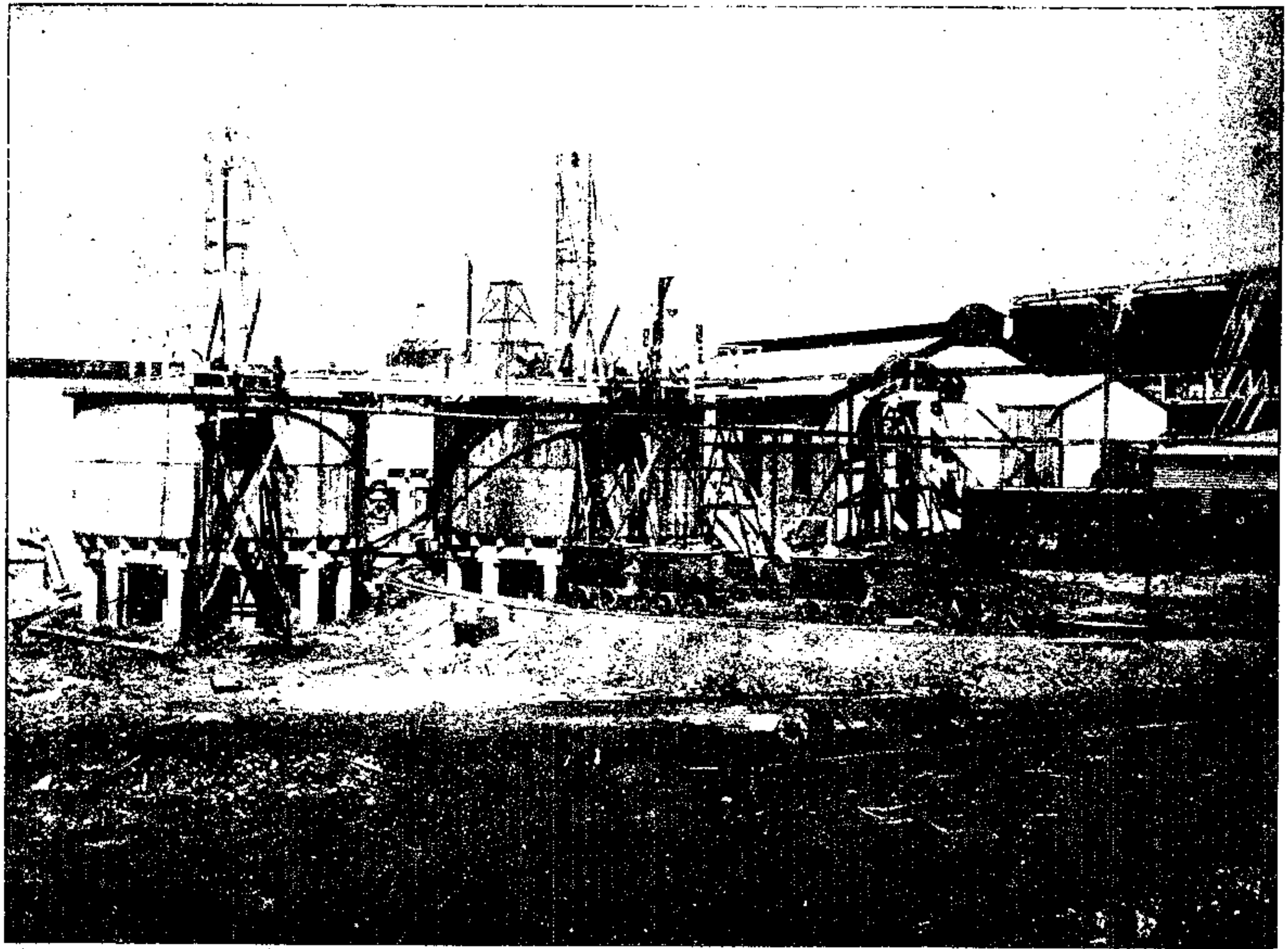
FROM KOOKYNIE TO LAVERTON.

KOOKYNIE.
MALCOLM.
LEONORA.
ANACONDA.
MURRIN MURRIN.
YUNDAMINDERA.
MOUNT MORGANS.
LAVERTON.



RAE BROS PHOTO PROCESS HOUSE 19 KING ST

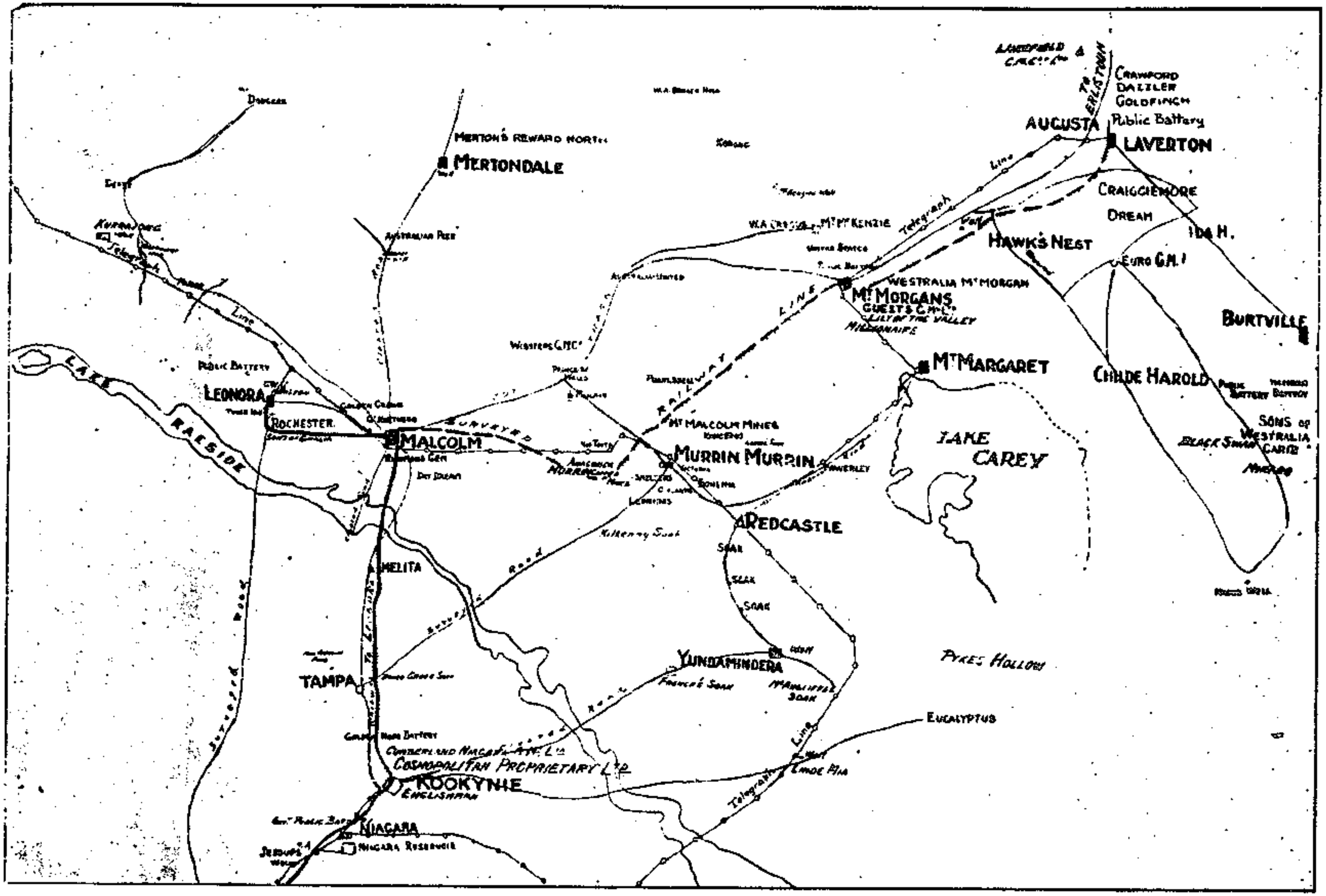
Printed at the "Morning Herald" Job Printing Department, St. George's Terrace, Perth.



CYANIDE PLANT—WESTRALIA MOUNT MORGANS GOLD MINES LIMITED.

The

North-Eastern Goldfields.



MERTONDALE
LAVERTON
AUGUSTA
CRAIGGIEMORE
HAWK'S NEST
BURTVILLE
MT MORGANS
WESTRALIA MT MORGAN
MT MARGARET
CHILDE HAROLD
LEONORA
ROCHESTER
MALCOLM
MURRIN MURRIN
LAKE CAREY
REDCASTLE
MELITA
YUNDAMINDERA
TAMPA
KOOKYNIE
NIAGARA
EUCALYPTUS
Pykes Hollow

ROUTE MAP.

The North-Eastern Goldfields.

FROM KOOKYNIE TO LAVERTON.

HOW TO GET THERE. WHAT IT COSTS.

INTRODUCTION.

"WHAT have you beside the Golden Mile in Westralia? Take that away, and there's nothing left." This is what a stranger within our gates might remark, and naturally enough, because the Golden Mile has been boomed the world over, and has established a unique record, so far as much boomed places are concerned, in that it has more than realised the most sanguine boomster's anticipations in actual results. The Golden Mile is in the East Coolgardie Goldfield, and may, for all practical purposes, be said to be "the" East Coolgardie Goldfield, and the output of that field is shown in the following table:--

EAST COOLGARDIE GOLDFIELD.

OUTPUT.

Year.	Quantity. Oz.	Value. £
1896	85,287	324,090
1897	300,037	1,140,141
1898	450,312	1,711,186
1899	923,617	3,509,747
1900	810,906	3,081,445
1901	1,033,670	3,697,833
1902	1,172,405	4,182,799
1903 (to May 31)	575,743	2,053,483

At £3 11s. 4½d. per ounce.

Average per ton of ore milled 1901—1.42oz.; 1902—1.31oz.

It is known to few, however, that, beyond Kalgoorlie, further north-east than the 90-Mile—or Menzies, as it is now known—lies a new Eldorado where Golden Miles are being gradually and steadily developed, and into this region—the Mount Margaret field—it is proposed in this small volume to take the visitor. Although one of the youngest goldfields, Mount Margaret ranks only second to East Coolgardie in its gold yield.

MOUNT MARGARET GOLDFIELD.

OUTPUT.

Year.	Quantity. Oz.	Value. £
1987 (from Aug. 1)	8,685	33,006
1898	43,267	164,413
1899	81,807	310,905
1900	141,523	537,787
1901	198,808	745,530
1902	216,637	812,389
1903 (to May 31)	87,576	328,410

At £3 15s. per ounce

Average per ton of ore milled 1901-1902, .76oz.

The Niagara district, in the North Coolgardie Goldfield, will be touched upon, because, although in a field distinct from the Mount Margaret, the growth of Kookynie and its surrounding mines is coincident with the progress of the district beyond Menzies, while the extension of the Menzies-Laverton railway had its first section here. In fact, Kookynie is a much younger town than Mount Morgans, which it bids fair to out-rival.

Also, the statistics as to population, the conditions of everyday life, the cost of living, and the cost of travelling, together with the route, will be interesting and valuable, not to the casual visitor alone, but to many to whom this rich country is a terra incognita at present, though they live in the State. By contrast with Kalgoorlie, the progress of these North-Eastern towns has been even more rapid than that of the metropolis of the Eastern Goldfields, which, less than a decade ago, was a dusty, scrub-covered desert patch, with just a few prospectors' hessian or bag humpies, while to-day there are well-made streets, lighted by electricity and planted with sugar gums and pepper trees along the edges of the footwalks; electric overhead trolly trams to convey the public speedily whither they wish, at moderate rates; separate cycle tracks in all the streets for those who use this popular means of locomotion; stone and brick buildings, of two or three storeys; hotels, which are not excelled by the finest in Perth in regard to appointments and cuisine; and last, but not least, water laid on by means of what may be truthfully said to be one of the finest engineering schemes of the century, generally known as the Coolgardie Water Scheme.

It may not be amiss, later on, to give a few details of this undertaking.

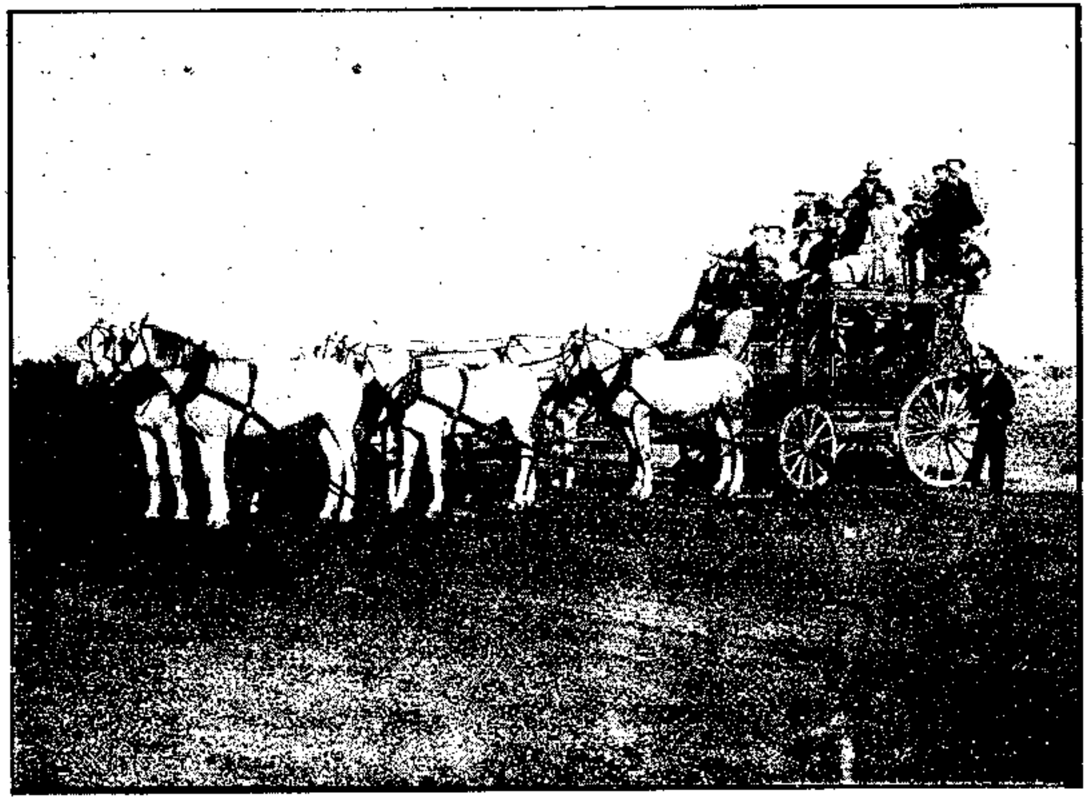
What does the traveller find in the Margaret field, and all within the space of five years? Big stone and brick hotels, lighted by electricity, and equipped in the most modern style; the streets well-formed and graded, and lighted by electricity; and water laid on—not from the great scheme hewever, but from the natural supply, for the Mount Margaret, unlike its elder sisters, the Coolgardie, East Coolgardie, North Coolgardie, and North-East Coolgardie fields, has abundance of natural fresh water, and embraces vast tracts of good pastoral country, so that it has its own meat supply—far better meat than in Perth—drawn from the herds of the Nor.-West, the stock being travelled overland

Moreover the field has been made the scene of an unique experiment in social legislation, for at Gwalia, two miles from Leonora, is the Government State hotel, or as it is facetiously termed "the Government pub." A view of it is given with details of its working, and particulars as to results to date. Lord Grey's scheme has worked wonders in the Motherland, and what the future may hold in regard to State hotels, depends largely on the success or otherwise of "the Government pub." at Gwalia.

To get down to bedrock. What every man wants to know about the "Margaret" is

(1) How to get there.
(2) What it will cost.
(3) What are the opportunities and openings offered for energy and capital.
(4) What is the cost of living.
(5) What are the conditions of life.

All these particulars are given in this book, and in order that what is set down may be more easily assimilated mentally, photographs of all places of interest, towns, mines, business premises, and so on, are reproduced. All particulars herein may be relied upon, as the details have been collated on the spot, and are acquired by actual experience, so that the value of the work lies in its accuracy.



A BACK COUNTRY COACH.

THE MOUNT MARGARET GOLDFIELD.

The Mount Margaret Goldfield, as before mentioned, ranks second in the State as a gold-producer, though only in the sixth year of its existence. Originally part of the North Coolgardie Goldfield, it now comprises three districts, Mount Malcolm, Mount Morgans, and Mount Margaret, and has a

total area of 42.252 square miles. The Warden's headquarters are in Mount Morgans, because of the central position of that town.

The field had practically to rely upon itself, as very little capital came from outside. In many instances crushings from the mines had to be depended upon to provide the machinery needful for further development. The district was also hampered by the lack of transit facilities, but this has been greatly relieved by the extension of the Government railway from Menzies to Malcolm and Leonora. The line is at present in course of construction to Mount Morgans, and thence it is proposed to take it to Laverton.

The methods adopted by the James Government, in erecting public batteries, will doubtless relieve to a large extent the hardships which in many cases have been endured by prospectors, who, having medium-grade propositions, frequently had to abandon their "shows" before they were sufficiently developed to warrant the speculator placing money in them. There are three State batteries on the Mount Margaret field, one at Leonora, one at Laverton, and another at Burtville.

The population was estimated to be, on December 31, 1902, 6,025 persons, distributed as follows:—Mount Malcolm, 2,741; Mount Morgans, 1,114; and Mount Margaret, 2,170.

The rain fall last year averaged 10 inches, and several market gardens are in full cultivation, and the vegetables are excellent and far superior to the imported, but the prices are rather high. Several pastoral leases have been taken up; the ruling price of meat being from 8d. to 1s. 3d. per lb., according to the "cut."

The rate of wages per week, as compared with East Coolgardie, is as follows:—

EAST COOLGARDIE.

Miners. Above Ground.	Underground.	Eng. Drivers.	Mechanics.	Carpenters.	Labourers
£3 10 0	£4 3 0	£4 5 0	£4 10 0	£4 10 0	£3 0 0

MOUNT MARGARET.

Miners. Above Ground.	Underground.	Eng. Drivers.	Mechanics.	Carpenters.	Labourers
£3 10 0	£4 0 0	£4 10 0	£4 10 0	£4 10 0	£3 10 0

The total unmber of miners employed on the field in 1902 was—Above-ground, 884; underground, 1,253; total, 2,137. In the East Coolgardie field there are 6,254 miners employed —3,230 above-ground, and 3,024 underground.

Taking the three districts separately, and including alluvial miners, the figures are:—Mount Malcolm, 964; Mount Morgans, 470; and Mount Margaret, 771.

THE RAILWAY JOURNEY.

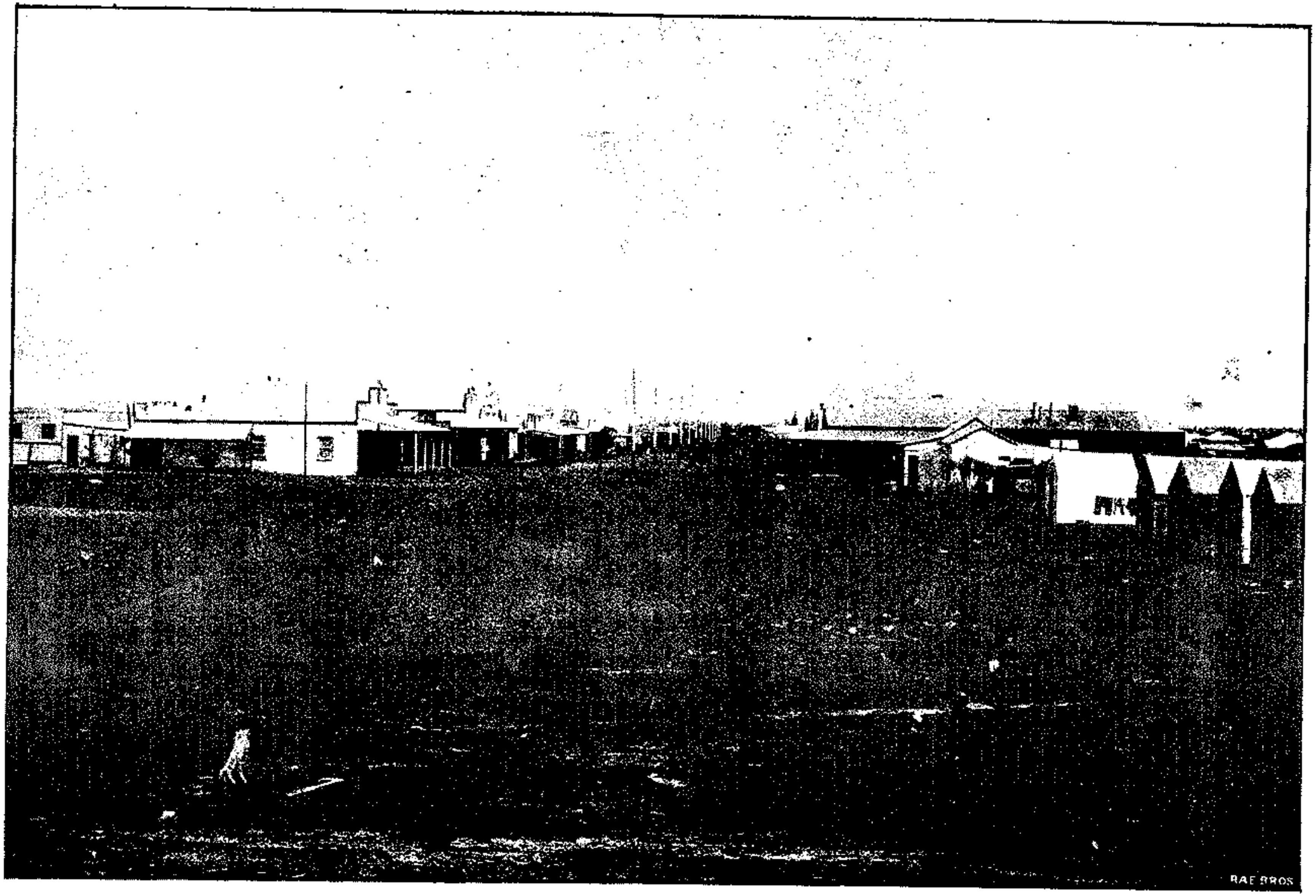
In order to make matters as clear as possible, the principal towns on the railway line after leaving Menzies will be dealt with first in the order they are reached, and it may be well to give the distance from Perth and the fares straightaway. The map will give the necessary idea of the locality more clearly than could be set down in writing.

Station.	Miles.	Fares. Single. 1st.	Single. 2nd.	Return. 1st.	Return. 2nd.
Niagara	489	£4 1 3	£2 10 8	£6 1 11	£3 16 0
Kookynie	493	4 1 11	2 11 1	6 2 11	3 16 8
Malcolm	521	4 6 7	2 14 0	6 9 11	4 1 0
Gwalia	534	4 8 9	2 15 9	6 13 2	4 3 2
Leonora	536	4 9 1	2 15 7	6 13 8	4 3 5

There are four trains daily to Kalgoorlie and their times of starting may be seen from the published time-tables. For the purpose in hand, however, the express, which leaves Fremantle at 6.40 p.m and Perth at 7.30 p.m. every day, except Saturday, will be taken.

Sleeping berths may be obtained at a cost of 10s. each, and these should be applied for early in the morning as there is a good deal of passenger traffic to the fields. The express is due at Kalgoorlie at 1.5 p.m., the following day. On the route refreshments and meals are always obtainable, the price being 2s. 6d. per meal; and due provision is made of time in which passengers may eat.

An hour is available at Kalgoorlie for luncheon and this costs in an hotel 3s., and the 3s. Zone may be said to be entered here—3s. per meal and 3s. per bed: 12s. a day—and this is the standard rate throughout the goldfields.



CUMBERLAND STREET, KOOKYINE.

Roy Millar, Photo.

The train for Niagara leaves at 2.15 p.m.—it is generally called the "Menzies train," because, until recently, when the line was extended, Menzies was the distributing centre—and is due at Niagara 8.25 p.m., Kookynie 8.31 p.m., Malcolm 9.56 p.m., Gwalia 10.29 p.m., and Leonora 10.35 p.m. Thus in round figures the journey to Leonora may be acomcplished in 26 hours, and without discomfort.

NIAGARA.

The glory has departed from Niagara, which in 1895 was a flourishing town. In the old days it was a coaching town and a busy centre. Now Kookynie has supplanted it, but there are many good shows round Niagara, and at the time of writing there were outward and visible signs of things taking a turn for the better.

Niagara is a "mud" town, nearly every building in the place being constructed of sun-dried mud bricks. In adobie building the clay is sunk in mould frames and allowed to settle and dry; in mud brick building each particular brick is formed and dried and then laid. These bricks are about four times the size of ordinary bricks and the buildings are very cool and present a solid appearance.

The population of Niagara is small—about 75.

There are four hotels, two stores, a butcher, and baker. The town possesses a post, telegraph, and money-order office.

The water supply is obtained from the Government reservoir; and the pan sanitary system is in use.

There are about 50 prospecting "shows" within a radius of two miles, and on the Eagle Hawk a 10-head battery is being erected. About a mile outside the town is a State battery and cyanide plant (10-head), which was started on public crushings in November, 1900.

Of the leases, the Opal, Pearl, Heather, and Pine Lodge have been sold to companies, the first being owned by the Hannan's Main Reef Company. They were all practically abandoned shows until the advent of the State battery.

The deepest shaft on the leases round Niagara is 180ft.—water level—and the ore bodies vary in size. The quartz is friable in character and easy to crush. In all 7,000 tons have been crushed at the State battery for a yield of 9,000oz.

There is in the town a Mechanics' Institute, in which is a library; and the attendance at the local school is increasing every month.

KOOKYNIE.

Kookynie, 493 miles from Perth, and 1,497ft. above sea level, is the town next Niagara.

The town, which has an area of two and a-quarter square miles, was incorporated on May 22, 1902; and is governed by nine Councillors, exclusive of the Mayor. Half-a-mile (of the 2¼ miles of streets, within its boundaries) has been formed at a cost of £23 per chain.

The total number of buildings within the municipality is 400, and the population 2,320, made up of 1,693 males, 331 females, and 296 children. The municipal rate is 1s. 3d. in the £. The sanitary system employed is that of sealed pans.

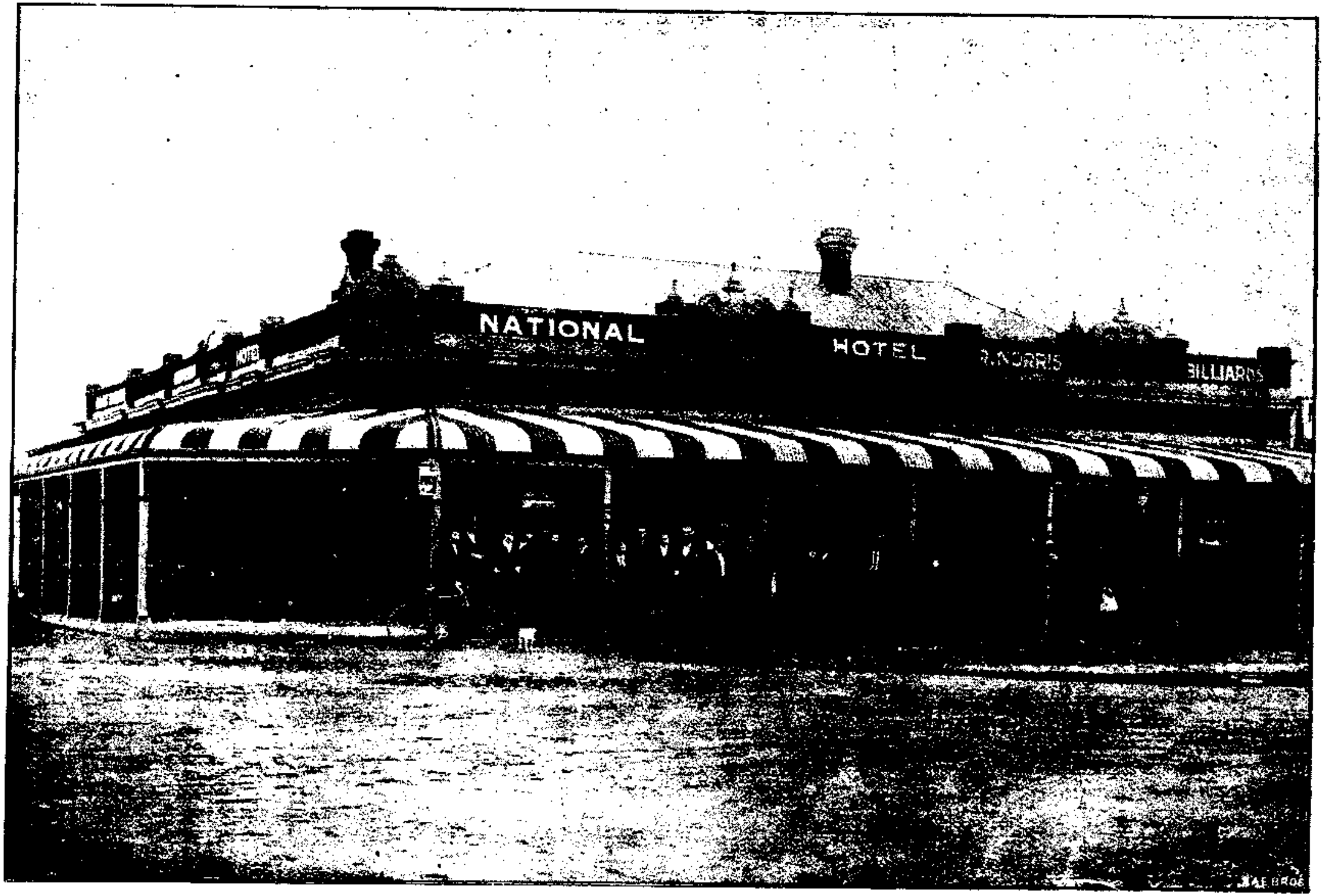
There are seven hotels and a workmen's club, five general stores, three drapers, and four confectioners and greengrocers, etc., besides stationers, tobacconists, and so on. There are a State school, hospital, and post, telegraph, and money-order offices. The water supply is derived from wells, and mains are being laid down for service in case of fire and for street watering. The water is fresh and of good quality, and the town has an excellent swimming bath, which is a great boon in the summer months.

An electric light installation to comprise, 7 arc lamps for street lighting, supplemented by 15 kerosene lights, is at present being established.

The maximum shade temperature recorded last summer was 112 deg. Faht., and the minimum, in winter, 46 Faht.

The town supports two newspapers, one published once and the other twice a week.

Fruit and vegetables of all descriptions are plentiful.



McADAM'S NATIONAL HOTEL, KOOKYNIE.

Banks also have branches in the town, and some very handsome brick buildings adorn the streets; which are very level, as the town is in flat country.

Many years ago the brick buildings were erected, long before anybody guessed that, within a year and a-half, the town would become what it now is. The rooms in both hotels are large and comfortable, and they are lighted by electricity.

THE KOOKYNIE HOTEL.

In contrast to each other may be cited Campbell's Kookynie Hotel (the first hotel in Kookynie) and McAdam's National Hotel, of which buildings illustrations are here given. Although the front of the Kookynie Hotel is not so imposing as that of the National, numerous additions in brick have been made in the back, but as a landmark of the early days the front remains almost indentical with what it was be-

Bathrooms are on the premises, and the traveller will find in regard to menu and appointments much to marvel at, considering the brief period in which all these things have been accomplished.

Last, but not least, the town has an excellent recreation ground and racecourse, and on the latter the Kookynie Turf Club hold three meetings annually.

THE COSMOPOLITAN GOLD MINE.

On the town boundary is the Cosmopolitan Gold Mine, which practically brought Kookynie into existence. The mine is owned by the Cosmopolitan Proprietary, Ltd.

The following is the output of the mine:—

		Tons	Ozs.	Value
1898	...	208	187	£698
1899	..	9,901	9,067	35,363
1900	...	15,430	14,246	54,992
1901	...	15,288	22,719	81,740
1902	...	57,171	50,222	181,991

The following are the monthly returns during the present year;—

1903		Tons	Value	Value per ton		
January	...	6,028	£14,244	£2	7	3
February	...	6,031	15,600	2	11	8
March	...	6,957	18,403	2	12	10
April	...	7,126	18,708	2	12	6
May	...	7,459	19,823	2	13	1
June	...	7,607	19,104	2	10	2
July	...	7,734	19,872	2	11	4
August	...	7,803	20,333	2	12	1
September	...	7,678	19,832	2	11	8

The depth of the main inclined shaft on September 30, 1903, was 1,135ft.

The general managers are Messrs. Bewick, Moreing and Co., the local superintendent being Mr. W. H. Shipman.

MALCOLM.

By the time this book is in type the railway line will, in all probability, have been completed to Mount Morgans, north-east of Malcolm, whence it will, at a later date, be extended to Laverton. At the time of writing, Malcolm is the terminus, but a branch line runs westward to Leonora.

Malcolm is an old town—so far as goldfields towns go—having been incorporated in October, 1900. It is 521 miles from Perth, at an altitude of 1,360ft. above sea level. The area of the municipality is one square mile, and its destinies are controlled by a Mayor and six Councillors.

The town is scattered in appearance and lacks compactness, there being many unsightly gaps along the building-line of its streets. There are seven miles of streets, of which 36 chains have been formed and four miles cleared. Sixteen kerosene lamps serve to light these streets by night.

Within the town boundaries are 210 buildings, and the population is 450, of whom 255 are males, 120 females, and 75 children.

The increase in the proportion of females to males in the older towns will be apparent and is in the natural order of things, as places become more settled and their permanency more assured. A municipal rate of 1s. 4d in the £ is levied; and the sealed pan sanitary system is employed.

There are five hotels in the town, as well as a brewery, and an equal number of stores. There are postal, telegraphic, and money-order offices; and a State hospital.

The rainfall per annum averages eight inches; and the water supply for the town is derived from five good wells, all equipped with windmills. The maximum shade temperature last summer was 120 deg. Fahr., and the minimum (winter) 34 deg. Fahr.

Vegetables are supplied from three local gardens, the supply being supplemented from Perth, which provides fruit also. Fresh milk is obtainable from a dairy in the town.

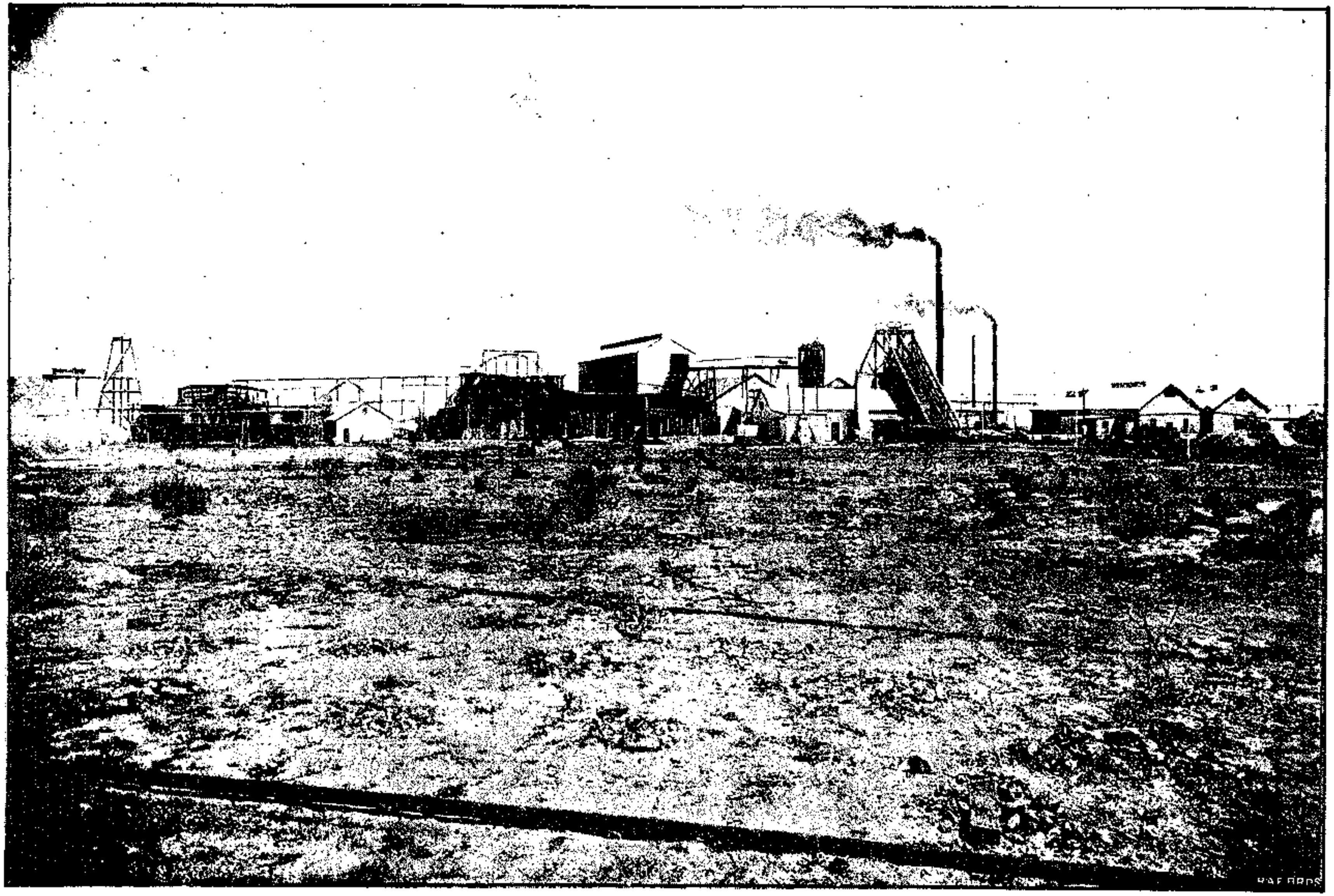
A local court is held monthly, and a warden's court fortnightly.

The Richmond Gem Gold Mine, which has passed through many vicissitudes, is working, and is just outside the town.

Twelve miles east is Webster's Find Gold Mine, owned by the Perseverance G.M. Ltd., and both of them are paying well.

The "Pig Well" leases are about 12 miles north of Malcolm, and these have been coming well to the front of late.

There is an hotel there at the parent lease, "The Flying Pig," which rejoices in the name of "The Wattle Bark Hotel"; and within a radius of a mile about 60 men are working. The



THE COSMOPOLITAN, KOOKYNIE.

Roy Millar, Photo.

chief "show is "The Harriston," named after its finder Harris, a drover for a Malcolm butcher. A recent crushing of 232 tons averaged 4oz. per ton.

MERTONDALE,

Where is situated the erstwhile famous Merton's Reward Mine, is eight miles further north.

At Mertondale there are three hotels and four stores, and at present it appears to be simply a question of the survival of the fittest. Mining matters are very quiet.

There is a cleared track to Mertondale via the Pig Well, and the journey may be accomplished either by horse and buggy, bicycle, or on foot. Of course, there are many other leases working in the district, as will be seen by the map, but the limited space at our disposal allows only reference being made to those, which are at the moment attracting attention.

Harking back to the railway, the next place is

GWALIA.

534 miles from Perth, where is situated the famous Sons of Gwalia Mine—and an unique experiment in social legislation, the Gwalia State Hotel, of which an illustration is given. This hotel was erected by the Government, from plans prepared by Mr. W. E. Robertson, architect, at a cost of £4,800, and its furnishings and stock cost another £1,200. It was built mainly for the benefit of the men working on the Sons of Gwalia Gold Mine, on the boundary of which it is situated. The hotel is comfortably equipped, and contains on the ground floor a bar-room, a bar parlor and billiard-room (all fitted with fireplaces), a smoking room, dining-room, kitchen, and offices, with stabling, etc., at the back. The hotel is of of brick, and is two-storeyed, with a wide balcony on the northern and western ends. Upstairs there are a drawing-room, and three single and three double bedrooms, all roomy and furnished with a due regard to comfort. The menu is excellent, and includes fresh meat, fresh fish, fresh milk, vegetables, and fruit. All liquors are of the best quality. Spirits are a shilling a glass, beer and "shandygaff" 6d. per glass. The hotel closes at 11 p.m. to the minute, no credit is given, and the moment it is deemed that a man has had enough to drink, more liquor is refused him. Of course, the bar is never open on Sunday. The hotel is controlled by a manager, who is paid a fixed salary, and has no interest or share in the profits whatever. With the exception that, in the Peoples' Refreshment Houses Association's Hotels in England, where the manager is allowed, in addition to his salary--a profit on non-intoxicants, the State Hotel at Gwalia is run on similar lines.

That it is a complete success was proved by the writer of this brochure, who "interviewed" 30 or 40 miners on pay-night and they were all unanimous that it was the best institution they knew. They were prevented drinking to excess, got good liquor, and thus saved money, because when there was no hotel there, they went to "shanties," got bad liquor, and more often than not were robbed when they lay stupefied through drink.

The Gwalia Mine pays once a month, and as some men, on the contract system, earn as much as £1 a shift, it can easily be estimated what this means—smetimes £26 for one "pay."

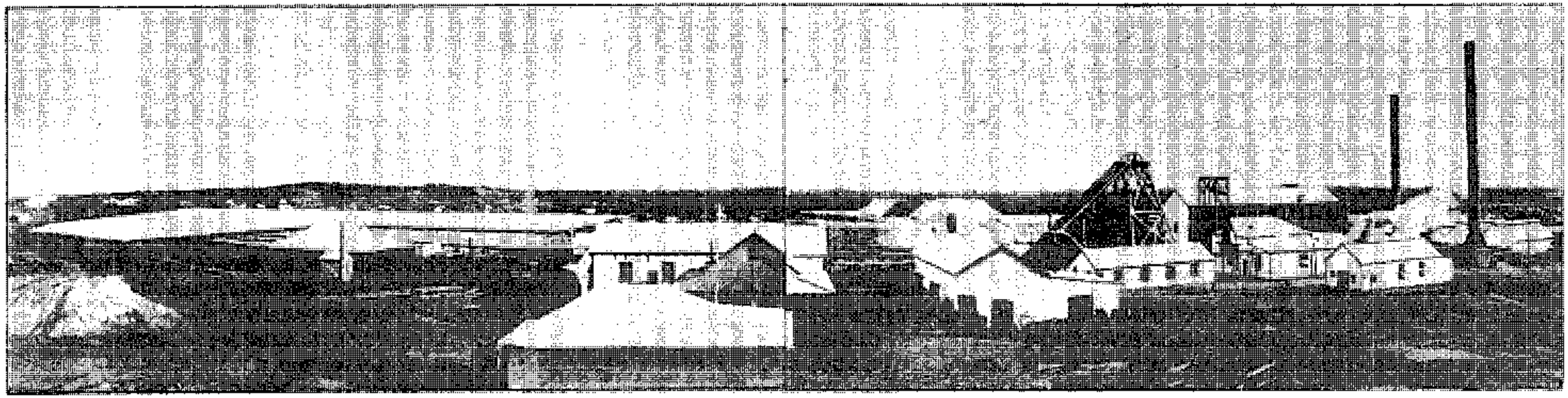
In conclusion, it is satisfactory to know that the State Hotel, which was only opened on June 3, 1903, is a paying concern, and the profits are increasing.

THE SONS OF GWALIA, LIMITED.

The Sons of Gwalia Mine, which is just over two miles distant from the township of Leonora, was discovered and pegged out by some Welsh prospectors in July, 1896, work being commenced on the leases in the September following.

The London and Westralian Exploration Company first obtained the property from the prospectors, and it was subsequently floated in London into the present company, with a nominal capital of £350,000, in £1 shares, 318,000 of which have been issued, fully paid up, to date.

The present company now hold in all 29 leases, covering 683 acres.



Roy Millar, Photo.

GWALIA GOLD MINE, GWALIA.

The mine is well equipped with all the latest machinery, including a Fraser and Chalmers' 50-stamp mill (with divided plates to allow the tables being scraped and cleaned up whenever necessary without the stoppage of a single stamp. A cyanide plant, capable of treating over 5,000 tons of sands monthly; grinding pans, agitators and filter presses for the treatment of concentrates, and a nest of Spitzkastins for settling of slimes.

The mill crushes on an average close upon 8,000 tons of ore per month, giving a stamp duty of 5.32 tons per 24 hours. From 4,000 to 5,000 tons of sands are cyanided monthly, and about about 100 tons of concentrates treated.

Since crushing was started in May, 1897, there have been put through the mill 362,623 tons, which have yielded in all 276,972 ounces of bullion, being an average extraction per ton to date of 15dwts. 7 grs., and giving a total value of £1,042,4 3 2s. 3d.

The Gwalia lode consists of a schistose formation, oxi-

dised for the first few levels, and gaining very slightly in sulphides as depth is attained.

The main shaft is down 1,555 feet on the incline, and 12 levels in all have been opened up, ore for the mill being obtained at the present time from eight of these levels.

The prospects of this property are, perhaps, better at date of writing than in any previous period of the mine's history. Under the superintendence of Mr. W. J. Loring, the mine has made rapid strides, both in development and economy of working, and it is now in the fortunate position of making a net profit of over £10,000 per month.

Two dividends of two shillings each per share have been paid to date, one in 1901, and the other in June, 1903, and at the last general meeting of shareholders in London, the Chairman of directors (Mr. Cyril Wranklyn) forecasted future dividends of two shillings each per share being payable every four months. We are given to understand that the present position of the mine fully bears out his prognostica-

STATE HOTEL, GWALIA. Roy Millar, Photo.

tions. The mine has as general managers the well-known firm of Bewick, Moreing and Co., their local superintendent being Mr. W. J. Loring.

LEONORA.

Leonora is 536 miles from Perth, and is a compact town, with many brick buildings. The population is 400, and the town is connected with the Gwalia by a steam tramway as well as by railway. A fine public hospital is situated between the town and the Gwalia. There is a local rifle club, and an excellent fire brigade, to aid whose efforts the town has been reticulated from a large reservoir, constructed on a natural eminence. The town possesses a racecourse and recreation reserve, both within easy access of the town. It also maintains a newspaper.

The largest building in Leonora is Thompson's Hotel, a fine two-storeyed brick structure, which contains nineteen rooms, exclusive of the bathroom, two parlors and the bar. The proprietor claims to have the finest stabling outside Perth.

The Tower Hill Mine, which belongs to the Octagon Explorers' Ltd., is one mile south-west of the town, and covers an area of 96 acres There are eight shafts on the property, and all but one are down to water level (70ft.). Independent of surface work, about 3,000ft. of crosscutting and driving have been done. It is a low-grade proposition, with large bodies of ore. One reef is 120ft. wide. A parcel of 1,000 tons was going through the Government battery in August, estimated to yield 6 dwts. 5grs. per ton at the mill, with 5dwts. 5grs. per ton in the tailings. The gold is worth £4 per ounce.

About four miles north-east of Leonora are the Ironstone leases, owned by a Westralian syndicate. The deepest shaft is 170ft.; and the reef averages about 5ft. in width. 1,400 tons were crushed, and yielded 1,500oz. of gold. The owners are now about to erect a 10-head battery.

From Leonora travellers proceed by road to Lawlers, about 87 miles north in the East Murchison Goldfield.

YUNDAMINDERA.

Having particularised these towns on the railway line, it may be as well to proceed to Yundamindera (originally known as "The Granites"), which lies north-east from Kookynie, about 38 miles, in the Yerilla district of the North Coolgardie Goldfield, and which is reached by coach. When the railway is finished the route will be via Anaconda. At present the coach runs from Malcolm via Anaconda to Murrin Murrin, and thence to Mount Morgans and Laverton. A connecting coach runs twice a week from Yundamindera to Murrin Murrin to pick up the main line coach. The fare is 30s. to Malcolm, and 15s. to Murrin.

This place and its surroundings were, for a time, kept back owing to the lack of crushing facilities, but a Huntingdon mill is now being erected by the Government, with the result that several abandoned "shows" have been again taken up and are working. The town is controlled by a progress committee numbering seven, and a health board, also composed of seven members. The double pan sanitary system is in use.

The town is fortunate in that the streets need no forming, being ironstone, but a rate of 1s. in the £ is levied by the North Coolgardie Roads Board, while a health rate of 6d. in the £ is also collected.

There are three hotels in the town. "The Granites," belonging to Mr. C. E. Williams, is a wood and iron building, containing 15 rooms. A feature of the hotel is a cool room for use in summer This has a trellis-work front, and hessian (a kind of coarse canvas) five inches from the corrugated iron to allow a draught to circulate. This is furnished with cane lounges, and is a great boon in the heat of summer.

Another hotel is worthy of mention, "The Bulletin," of which Mr. C. B. Webb is proprietor. "The Bulletin" Hotel takes its name from "The Bulletin" newspaper, to which its proprietor is a constant contributor. The picture of the building (here reproduced) shows what may be termed a typical goldfield's hotel of the early type—in between the hessian and brick age, so to speak.

THOMPSON'S COMMERCIAL HOTEL, LEONORA.

A BUSH PICNIC, YUNDAMINDERA.

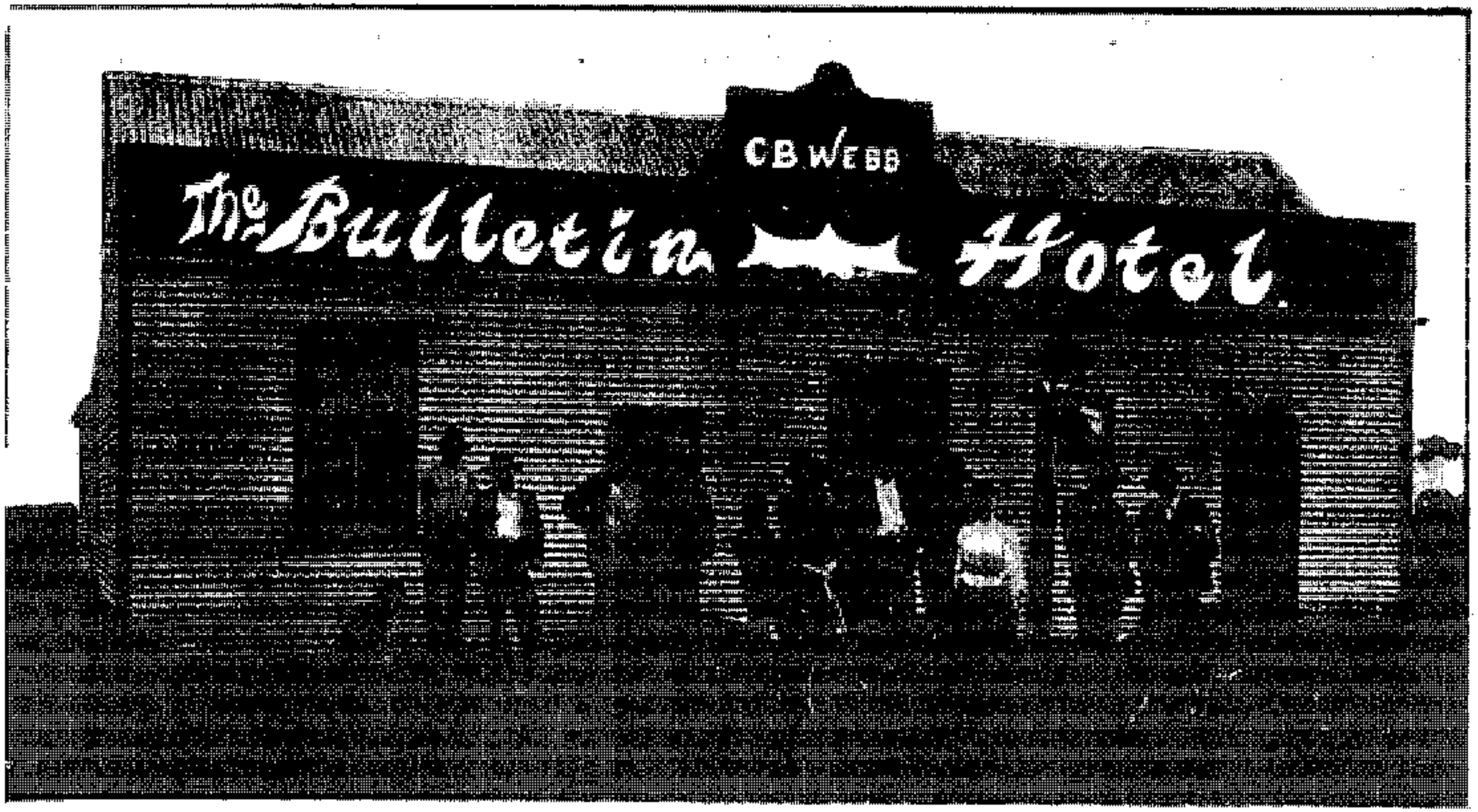
THE GRANITES HOTEL, YUNDAMINDERA.

There are two general stores in the town, two draper's shops, a baker, a butcher, and a hairdresser.

The Australian Workers' Association have a hall here, in which dances take place, while it is used as a half-time school and as a church, occasionally, when a clergyman visits the town. The town does not possess either a doctor or chemist. There are post, telegraph, and money-order offices. A tender has been let for the erection of a lock-up, but at present prisoners are chained to a tree, like wild beasts, their only shelter being that of a tent.

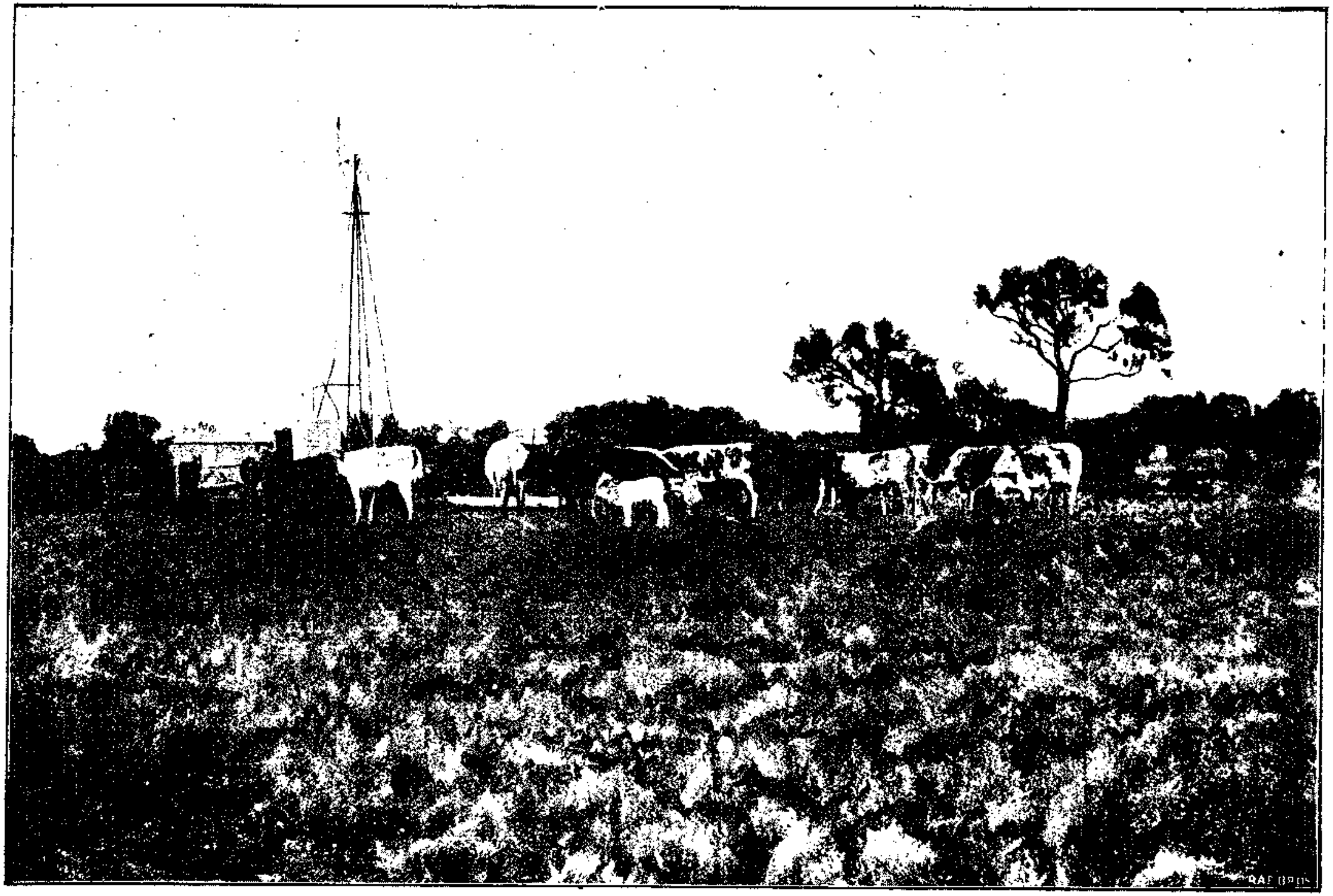
Vegetables are supplied by travelling hawkers, but there is no lack of good food, as the following meal, partaken of in one of the hotels will testify:—Vegetable soup, roast beef, potatoes and cabbage, rhubarb pie with fresh cream, cheese, etc. The water supply is derived from a Government well and from soaks.

An opportunity occurs right here, as the Americans would say, to describe a typical goldfield's town store, and this will very well stand for all of them. At the same time it will give those unfamiliar with colonial life, an idea of the vicissitudes a man has to undergo. S. J. Ottery started originally at Yerilla, but the place went down, so he packed up his goods and chattels and went to Pendinnie Soak, and, later, moved on to what was then the scene of a new "rush"—"The Granites." Fortunately, as the place progressed, he kept pace with it. The way the goldfield's storekeeper runs his business is not to sit down and wait for chance trade. One "round" in a cart is 30 miles. Goods are taken out and orders for the following week obtained, and so on. An idea of the varied and comprehensive character of the articles kept in stock by a goldfield's storekeeper may be gathered by the following list jotted down casually after glancing round the in-



THE "BULLETIN" HOTEL, YUNDAMINDERA.

terior of Ottery's:—Butter, eggs, tinned meats, milk and vegetables, chains, linoleum, straw matting, nails, tin trunks, flock pillows, canvas water bags, enamelled iron, fellmongery, tinware, general ironmongery, mining tools, explosives, leather belts, dungaree and tweed clothing, boots, kerosene, corrugated galvanised iron, timber for building purposes, padlocks and penknives, and heaven only knows what besides. This ought, however, to serve as a guide to anyone wishing to go storekeeping on the goldfields. It is apropos in this connection to give the prices current of food-stuffs in the town:—Potatoes are 2½d. per lb.; butter, 1s. 10d. per lb.; meat (tinned) 11d. per tin; flour, per 50lb. bag, 12s.; jam (2lb. tins), 1s. 1d.; tea, from 1s 6d. to 2s. 6d. per lb.



PENDINNIE STATION.

PENDINNIE STATION.

As mentioned in the prefatory remarks, good pastoral country exists on the North Coolgardie and Mount Margaret Goldfields, and the following account of Pendinnie Station, 9½ miles south of Yundamindera, and 42 miles east of Kookynie, should be interesting.

About five miles out from Yundamindera a halt was made at the Pendinnie Soak Hotel, a wayside house constructed of sun-dried bricks, and the front of which was covered with creepers, which made the otherwise ugly building look quite attractive. Hard by, is a garden, where the following vegetables are grown, and it may be as well to give the retail prices at the same time:—Lettuce, 4d. and 6d. a head; cabbage, 4d. per lb.; silver beet, 5d. per bunch; turnips, 4d. per bunch; and radishes, onions, and parsnips, all 4d. per bunch. Some fine water melons are also grown.

Refreshments having been partaken of, a fresh start was made, and Pendinnie Station was reached shortly afterwards.

The station, which is held by Milbank and Co., under 30 years' pastoral lease from the Government, comprises 458,000 acres. Sheep, cattle, and horses are running, and the accompanying illustration will give a good idea of the fattening qualities of the herbage, which consists of salt and cotton bush, kangaroo, mulga, and spear grasses. The country is thickly timbered with stunted mulga, cork, and salmon gum trees. There is, likewise, plenty of milk bush and wild geranium, both of which are good for fodder. The soil is sandy loam, in granite country, bisected by low ridges. The land is undulating.

To illustrate how luxuriantly kangaroo grass grows in the creeks, "The Bungalow," as Mr. Milbank's house is called, is thatched with grass that grew 6ft. and 7ft. high. Water for the homestead is obtained from a well 36ft. deep; it is of excellent quality, almost equal to rain water. There is a bore hole 40ft. deep on the centre of the run, about six miles from the homestead, and another is to be put down at "Marloo," the out-station.

A nice garden has been laid out near "The Bungalow," and here were growing in profusion lettuce, beetroot, cabbage, onions, swede turnips, and melons.

A large number of pear, peach, apricot, apple, lemon, and orange trees have been planted and are flourishing. Cape gooseberries grow almost wild, while a young grape vine is already over 8ft. high, all of which testifies to the prolific nature of the soil. The grass is best when the summer rains come on, but there is plenty of herbage throughout the winter.

Wild turkey, emu, kangaroo, and wallaby abound, so there is no lack of sport for spare hours.

"The Bungalow" itself is a picture, covered with wild native flora, with mignonette and other flowers blooming hard by. The thatched roof keeps the house very cool, and on the hottest day in summer it is never more than 65 deg. Faht. inside. Pepper trees aid in lending their graceful shade. Truly, a pleasant picture!

In due time the party returned to Yundamindera, and then drove to Mt Morgans via Redcastle, where there is a wayside hotel. Redcastle lies about 11 miles north-west of Yundamindera. Changing our course again, we bore north-north-east for Mt. Morgans, which was reached in due course.

Between each of the places visited by road, a day's journey may be reckoned, unless otherwise specified.

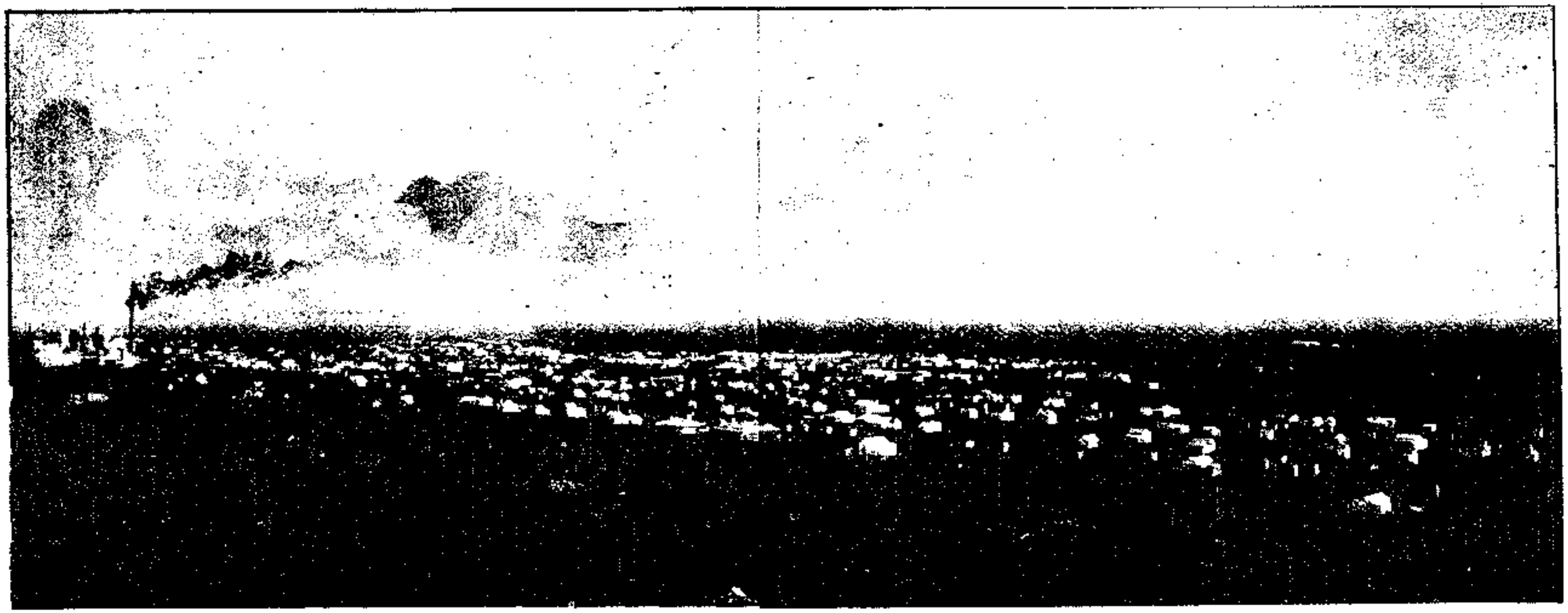
MT. MORGANS.

Mt. Morgans, which has a population of 1,250, is 563 miles from Perth, and 1,573ft. above sea level. It was incorporated in September, 1900, and has an area of about 1,112½ acres.

There are about 500 buildings within the municipality; and the streets, which cost from £3 10s. to £15 per chain to form, are lighted by electricity.

The town is built on an ideal site, which gently slopes on three sides, while the hill, on which are situated the mines, forms a striking background on the east.

There are six Councillors and the Mayor to look after the welfare of the citizens. The sanitary system is the duplicate sealed pan, and the rates are 1s. 3d. in the £.



PANORAMA OF MOUNT MORGANS. Roy Millar, Photo.

There are six hotels, four general stores, two chemists, tobacconists, stationers, hairdressers, butchers and bakers' shops. Most of the buildings are of brick. The A.W.A. have also a large hall, and there is a Workmen's Club. A Government hospital stands on a rise to the west of the town, and is one of the finest on the field.

The town also possesses a brewery and an iceworks and cool-storage house, which are necessary, seeing that last summer the thermometer recorded 122deg. Faht. in the Council Chamber, which is, however, a galvanised iron building.

There is a vegetable garden not far from the town, and the prices are only slightly in excess of those charged in Yundamindera. Fruit comes from Perth, and is dear, oranges costing 3s. per dozen. The water supply, which is derived from wells, is slightly brackish, but of fair drinkable character.

Mt. Morgans is the seat of government, so to speak, for here the warden resides, whence he pays periodical trips to Malcolm, Laverton, Leonora, etc. The town possesses a newspaper; and, as was remarked earlier, will probably be connected by railway ere this book is in type. The current price of fresh meat is from 1s. 1d. to 1s. 5d. per lb.

THE WESTRALIA MT MORGANS' GOLD MINE.

The mine, which was responsible for the existence of the town of Mt. Morgans, is a property owned by the Westralia Mt. Morgans' Gold Mines Co., Ltd., and upon this mine the town at the present principally depends.

It was taken up by the prospectors about 1896, and was later sold to a limited liability company, which was formed in Perth in 1897, by Mr. A. E. Morgans, M.L.A., after whom the mine and town were named. In 1899 the head office of the company was transferred to London.

The plant at first was a small one, and comprised two Tremain mills, which commenced operations in 1898, and treated 5,000 tons of ore, which yielded approximately 4oz. to the ton.

The Tremain mills were superseded by a 20-head stamper battery in July, 1899, but, as development work went on, large bodies of ore were opened up, and it was found necessary to increase the plant and a 60-head mill with King engine, self-feeders, rock crushers, and ore bins were erected in 1902. Thirty heads of the new mill have a falling weight of 1,250lb. per stamp, and the other 30 have a falling weight of 1,500lb. per head.

An air compressor (Corlis type) has been erected, which is capable of operating 25 large size rock drills.

The mine is equipped with electricity, and two dynamos each of 120 h.p. have been installed. These supply current for lighting the mine and town. Current is also derived from these dynamos for operating motors in the carpenters' and fitters' shops and cyanide and slimes plants.

Power for driving the plant is supplied by five 125 h.p. Fraser and Chalmers' multitubular boilers, and four 106 h.p. Babcock and Wilcox multitubular boilers.

At the No. 1 level the lode averaged 15ft. in width, and its value is over 30dwts. per ton.

At the No. 2 level the lode has been proved for a length of over 700ft., and averages over 20ft. in width and over 1oz. per ton in value.

At the No. 3 level, neither the full length nor the full width of the lode has been proved. North and south of the main crosscut at this level the lode has been opened out to an average width of 50ft. (in places 90ft.), for a length of 750ft., and carries good grade milling ore.

At the No. 4 level the main lode was recently intersected for a width of 40ft., and it carries good milling ore at the point of intersection. Driving on the lode was proceeding at the date of publication. 5,000 tons of ore have been stoped from this level.

The nominal capital of the company is £125,000 in 500,000 shares of 5s. each, of which 480,000 have been issued, and the following details are interesting and instructive, more particularly as it will be observed that the £15,000 in excess of the nominal capital has been returned in dividends, besides which all the working expenses and equipment have been paid out of the earnings of the mine.

Total tonnage treated to August 12, 1903 ...	156,567
Total yield to date	174,741oz.
Total value of same	£639,347
Average per ton	1oz. 2dw. 8g.

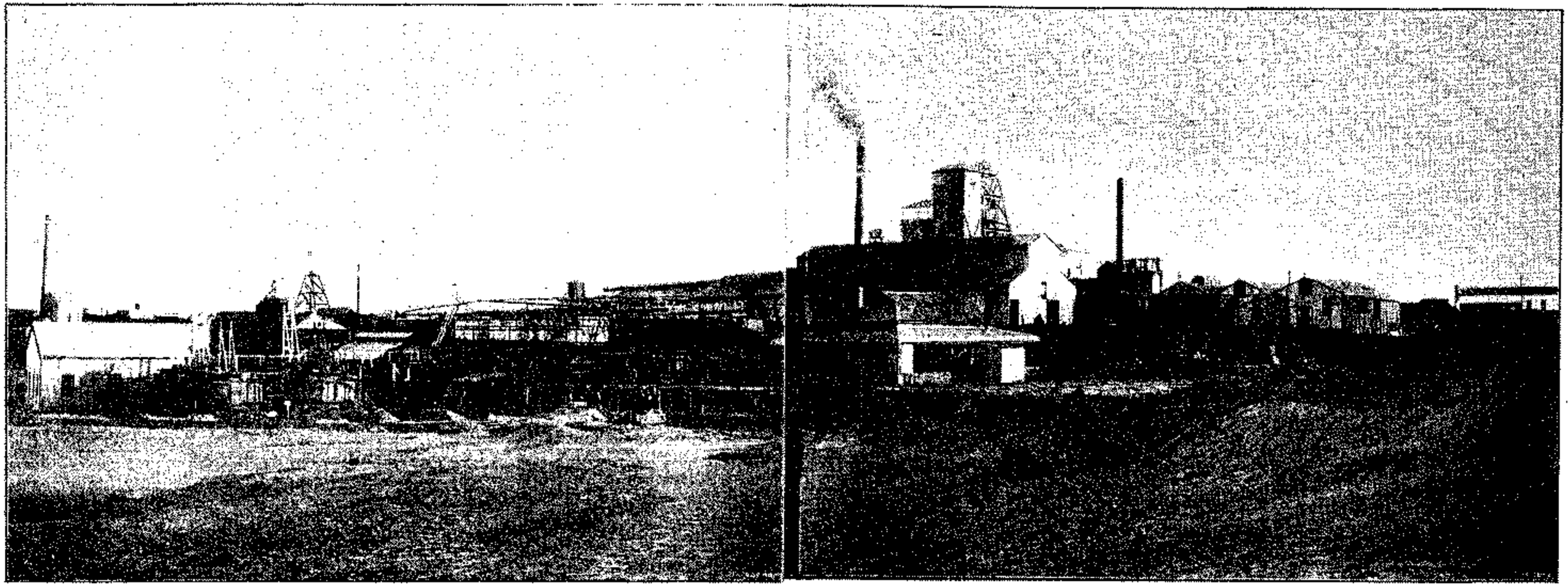
Present working cost per ton, including extraction, milling, cyaniding, and filter pressing 24s.

Dividends paid as shewn below:—

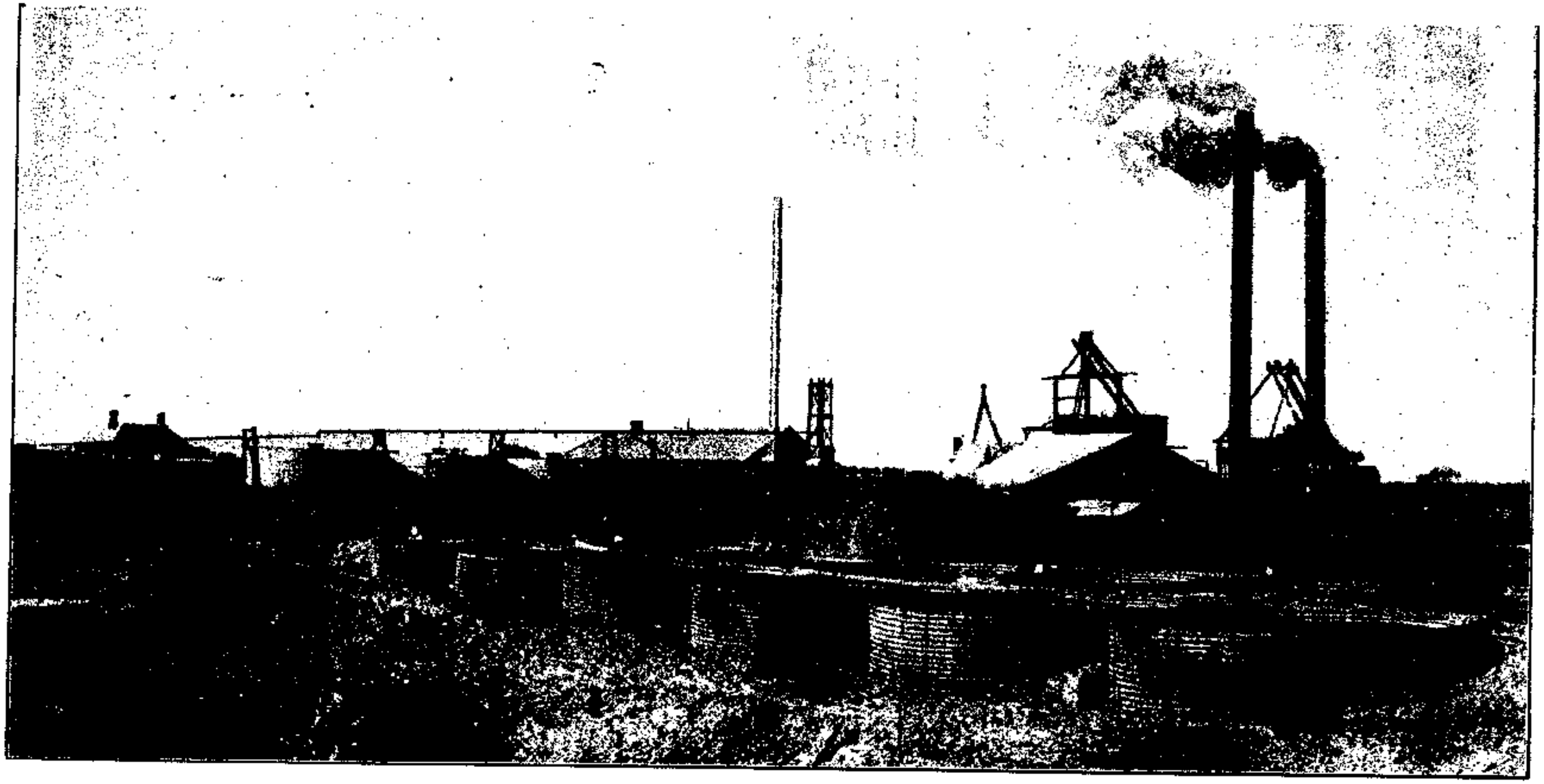
	£	s.	d.
To December, 1900	31,902	8	0
To December, 1901	44,350	16	0
To December, 1902	64,350	0	0
	£140,603	4	0

Besides the Westralia, the are the Guest's Mine, the Millionaire, Lily of the Valley, and Fire King, all adjoining.

On the north of the Westralia is the Mt. Morgans Consols (owned privately), a 24-acre lease, on which there are three shafts. Two are down 135ft., and the other has been sunk



WESTRALIA GOLD MINE.



LANCEFIELD GOLD MINE.

110ft. In the last there are two reefs at the 50ft. level, one about 18ft. wide, and the other about 30ft. At the 110ft. level the first reef is small, but there is another 40ft. wide, and the values in the latter are 15dwts. for about 15ft., while the balance is estimated to go 8dwts. A tunnel has been put in on the eastern side of the hill, and there is stone valued at 1oz. per ton in this, the reef being about 5ft. wide.

About one mile east, on the flat, some other leases are being worked, among them the Transvaal, belonging to Walter Hamblin, and this has been giving a good return for two or three years past. A five-head battery and cyanide plant is also owned by Hamblin, and here parcels are crushed for the public.

LAVERTON.

Proceeding 24 miles in a north-easterly direction we reach Laverton, and this town will also shortly be connected with the metropolis by the railway, but at present is reached by coach, which runs daily. It is named after Dr. C. W. Laver (brother of Frank Laver, the well-known cricketer), who was largely identified with its early progress.

It is, approxamitely, 590 miles from Perth, and has 300 inhabitants, of whom 80 are females, and 25 children. Its local government consists of a progress committee. Laverton possesses four hotels, and six stores, a butcher, baker, and two breweries. There are post and telegraph and money-order offices, and a Government hospital. The sanitary system is that of the sealed pan; and the water supply is derived from wells.

The maximum shade temperature recorded last summer was 112 deg. Faht., and the minimum 32 deg. Faht., so that the extreme from frost to great heat is apparent. However, owing to these towns being so far inland and at such an altitude, a temperature of 85 deg. on the coast is much more enervating and exhausting than 112 deg. on the goldfields. The rainfall per annum averages 12 inches.

Laverton possesses a weekly newspaper. There is an excellent recreation ground and a racecourse.

Vegetable gardens are within a short distance of the town. The Government battery is a great boon to the prospectors of the district.

The current prices for "tucker" are:—Tinned meat, 1s. per tin; flour (50lb. bag), 11s. 6d.; potatoes and onions, 3d. per lb.; sugar, 4½d. per lb.; jam, 1s. 2d. per 2lb. tin; tea, 1s. 9d. to 2s 9d per lb.

THE LANCEFIELD.

The Lancefield Gold Mine, which is the property of the Lancefield Gold Mining Co., Ltd., well deserves a full account of its progress, as it is essentially locally-owned, and has been developed purely out of its own earnings.

It lies five miles west of Laverton, by a cut track, and comprises 87 acres, and was first discovered by a prospector named Lemon, hailing from Lancefield, Victoria—hence the name of the mine. It was bought by a syndicate, which included the discoverer. They leased the battery from the old Quartz Hill Reward Mine (now known as the Euro) at £12 per week, with the option of purchase at the end of 12 months, which option they exercised and purchased out of the proceeds from the mine. Progress continued to be satisfactory, and in September, 1900, the syndicate was transformed into a limited liability company, with a capital of £25,000 in £1 shares fully paid. Out of these shares 3,400 have not been issued.

The deepest shaft is a vertical one 220ft.; while the main underlay shaft is down 200ft. on the incline. There is a most complete plant, and it must be remembered that all of this has been paid for out of earnings.

This plant comprises a 20-head stamper battery (fitted with rock breakers and self-feeders) and a cyanide plant of 1,600 tons capacity. Water, which is drinkable and is used in the boilers, was originally struck at 30ft., and they are now pumping at 200ft. by a Cornish lift pump, with a capacity of 5,000 gallons an hour, and this pump lifts from the incline shaft and discharges from the vertical. In order to avoid shifting the pump from its original position, a connecting

A WATER HOLE, YUNDAMINDERA.

beam from the mouth of the incline to the mouth of the vertical was put in, and this measures the exceptional length of 300ft.

A new cyanide plant with a capacity of 2,000 tons a month is being erected: and two 50-cake 3in. Dehnes' filter presses are being put in.

Steam power is derived from two Cornish and one multitubular boiler and there is an air compressor. Everything is done on the mine, there being a fitting shop with lathes, etc.

The buildings are constructed of sun-dried bricks and comprise:—Manager's house, offices, assay and retort houses, store room, and blacksmith' shop. All these are neatly finished, and are plastered inside and out.

The Lancefield is a low-grade proposition and is an object lesson in what can be accomplished by careful management. The ore averaged about 18ft. wide for a distance of 1,000ft. in the No 1 level; and in No. 2 level averaged about 15ft. for 300ft.; at No. 3 level it is 26ft. wide, and assays 10½dwt. per ton (fine gold) It is a blue mineralised, free-milling quartz.

The crushings since the syndicate first took the mine over are as under:—

	oz.	dwt.
By battery, 68,409 tons for	13,793	14
,, cyanide, 39,982 ,, ,, ...	16,795	15
	30,589	9

Leaving 28,427 tons of slimes on hand, which will average about 6dwt. to the ton.

About £70,000 has been disbursed in wages since the company took the mine in September, 1900, £19,000 having been expended on the plant and development work. £12,240 has been disbursed in dividends sine the same date.

A new brick on stone extraction house was going up at the time of the writer's visit. The history of this mine is particularly interesting, when it is known that the company consists, with hardly an exception, of the original shareholders, the majority of whom live there, and work on the mine.

Adjoining the mine are gardens, and one of these, a homestead area of 50 acres, deserves more than passing notice.

It was originally taken up by one of the proprietors of the Lancefield, Mr. Cameron, who afterwards disposed of it to Mr. John M'Farlane. That the soil is productive, may well be judged, when it is stated that pumpkins, melons, vegetable marrows, Turk's head, potatoes, and cabbage grow to magnificent proportions. Rock melons have been grown up to 60lb. in weight. The prices obtained are:—For melons (wholesale), 1½d. per lb., retailed at 3d. per lb.; potatoes, 4d. per lb. Lettuce, beetoort, and Cape gooseberries flourish, and a specialty has been made of vine growing, besides planting oranges, lemon, apple, peach, apricot, loquat, plum, and fig trees, all of which thrive. The owner expects to have about two tons of grapes for the current season, and these will easily fetch 1s. per lb., so that the venture promises to be profitable.

The whole area is irrigated by water obtained from the Lancefield mine, and this is run along channels.

THE CRAIGGIEMORE.

The Craiggiemore is another important mine, and lies about the same distance from Laverton as the Lancefield, only in the opposite direction. It was discovered in 1896 by Duncan Rose, Alex. Fraser, and Alex. M'Phail. Dr. Laver later on became interested in the property and floated it in England The area of the mine is 100 acres. The plant is complete and up-to-date and includes battery, cyanide plant, etc. The ore bodies are large, but of low-grade.

THE IDA H.

Seven miles out of Laverton, on the track to Burtville, is the Ida H. Mine, which is turning out well. The name is one to arouse curiosity, and, as apparently it has has not been recorded before, it may be interesting to know that the mine was christened after the daughter of the prospector, "Dick" Heaphy—hence Ida H.

The nominal capital of the company is £60,000, in originally 60,000 shares of £1 each, now cut up into 5s. shares,

CAMEL TEAM AND WAGON.

making 240,000 shares of 5s. each, 6,000 £1 shares, or now 24,000 5s. shares being held in reserve, leaving 54,000 £1 shares fully subscribed.

This company acquired the property from the prospectors about November, 1900, and, after a considerable amount of development work had been done, commenced crushing in November, 1901, and up to September 30, 1903, had crushed 21,874 tons of ore, yielding 24,784oz, being an average of 1oz. 2dwt. 15gr. per ton; gold valued at £96,720, and have paid in dividends equal to 50 per cent. in 1902, and 30 per cent. up to September of the present year, making 80 per cent. up to date.

The reef, which averages about 2ft. wide, has been followed on the 100ft. level a distance of 1,300ft., and at the 200ft. level a distance of 1,090ft., the ore raised and crushed being mainly taken from these two levels.

At the 300ft. level the reef has been driven on north and south a distance of 270ft., and at the 400ft., the deepest level, 100ft.

The main shaft has been sunk a depth of 420ft., at which depth a plentiful supply of salt water for battery purposes is obtained.

The mine is equipped with a 10-head mill and cyanide plant, and is now averaging about 1,150 tons per month.

BURTVILLE.

Burtville is about 19 miles from Laverton, to the south-east, and is 628 miles from Perth. It is a very new town, with a population of about 400 for the town and district, of which total 30 are females, and 16 children. There is a progress committee of seven; and a health rate of 6d. in the £ is levied.

There are two hotels, and three stores. The water supply is derived from a Government well; and the sealed pan sanitary system is used. The postal duties are discharged by a civilian, who is paid about £40 per annum by the Government. The conditions of life are not too hard now, fresh lettuce and cow's milk being obtainable. Burtville possesses a half-time school. There is a 10-head State battery and also a five-head battery—the Burtville Ore Reduction Works, while the Sons of Westralia Mine also crushes for the public.

The Sons of Westralia was the first lease taken up, in September, 1899. It is situated four miles south of Burtville, and is owned by Mr. Maurice Brown. There is a 10-head (850lb.) stamp battery, which was erected in February, 1902, and a cyanide plant was put up about the same time. There are two main shafts on the property, the deepest being 120ft. Water is reached at 100ft. The water is brackish, but there is not enough mineral in it to injure the boilers. Part of the equipment includes a condenser, with a capacity of 4,000 gallons in 24 hours.

The property comprises two 24-acre lease blocks—The Sons of Westralia, and the Great Westralia. The battery is on the Sons of Westralia, and so is the main shaft. The reef is about 2ft. wide, and the character of the stone is free-milling quartz.

About £28,000 worth of gold has been won so far, and the mine paid its way from the start.

On the Great Westralia the reef is 4ft. to 5ft. wide, and averages about 12dwt. per ton.

The battery crushes for the public at 20s. per ton, within a radius of two miles, and for the furthest part of the field for 23s.—any sized parcel, and cyaniding is done on the basis of a 4½dwt. extraction. There are about 50 leases in the district, in the prospecting stage, with average crushings of about 2oz. per ton.

The Karndale is about one mile south, and its deepest shaft is down 110ft. The reef is about 4ft. wide, and the crushings average 35dwt. per ton.

The Rock of Ages is about three miles in the same direction, and its crushings average 2½oz.

The Wanderer lies about one mile north-east; the reef averages 2ft. in width, and the crushings about 2oz. per ton. The deepest shaft is down 100ft.

The Tempus lies three-quarters of a mile north, and has a reef about 1ft. wide, which gives crushings averaging about 3oz. per ton, and the deepest shaft is 90ft.

The Mikado, with a reef about 6ft wide, averages about 18dwt. per ton.

The Government battery at Burtville has 10-head of stamps, 1,000lb. each, and there is a compound condensing engine capable of driving 40 head. There are also two Berdan pans, and steam is generated by two boilers. There are two settling pits to each five head of stamps, and two settling dams for water.

The Carib, four miles south-east of the town, and 24 acres in area, had just been sold to a London company at the time of our visit. The lode is about 6ft. wide, the reef about 2ft. 6in. The average was 35dwt. to 2oz. per ton, and the gold is worth £4 1s. 7d. per oz.

Fresh meat is obtainable in Burtville at 1s. 2d. to 1s. 3d. per lb., while tinned meat is sold at 1s. per tin. Potatoes fetch 3d. to 4d. per lb.; butter (box), 2s. 3d. per lb.; milk (condensed), 10d. per tin; flour, 12s. 6d. per 50lb. bag; tea, 1s. 6d. to 2s. per lb.

After leaving Burtville a return was made to Laverton, and thence a trip was made to Erlistoun. The return journey was accomplished via Laverton to Mt. Morgans, whence a route was followed via Murrin Murrin to Anaconda (21 miles south-west of Mt. Morgans), and thence west-north west 17 miles to Malcolm. As mentioned before, the coaches run this way, but the railway, which goes the same way will be completed by the time this brochure is issued from the press.

MURRIN MURRIN

At Murrin Murrin the Malcolm Mines Ltd are doing development work while public crushing is undertaken with the 50-head battery There is a cyanide plant, and a slimes plant is being put in. The main shaft is down 600ft on the underlay, but the stone, which was good down to 200ft., has decreased considerably in value. Prospecting is now going on in the deeper levels.

A short distance away is the Malcolm Proprietary Extended, owned by Wm. Hill. He started originally with two 3-head mills, but the mine has opened up so well, that he has now a 10-head battery and cyanide plant. The deepest shaft on this lease is down 120ft., and the stone averages about 1oz. of free gold per ton.

About four and a-half miles further on is the Hard Case, a lease which is reported to be very rich. This is worked by a man named Mitchell, and his wife, the lady taking a due share of the work with her husband. There are numerous other prospecting "shows" about.

ANACONDA.

There is a fair amount of settlement at Anaconda, and the care of the town rests with a progress committee of seven. No townsite has yet been proclaimed, but 64 residence areas have been surveyed. The population is about 350, of whom 30 are females, and 12 children.

There are about 36 buildings of all kinds within its surveyed limits, and of these, two are hotels and two stores. There are also a chemist, newsagent, and fruiterer.

Anaconda has no sanitary system at present.

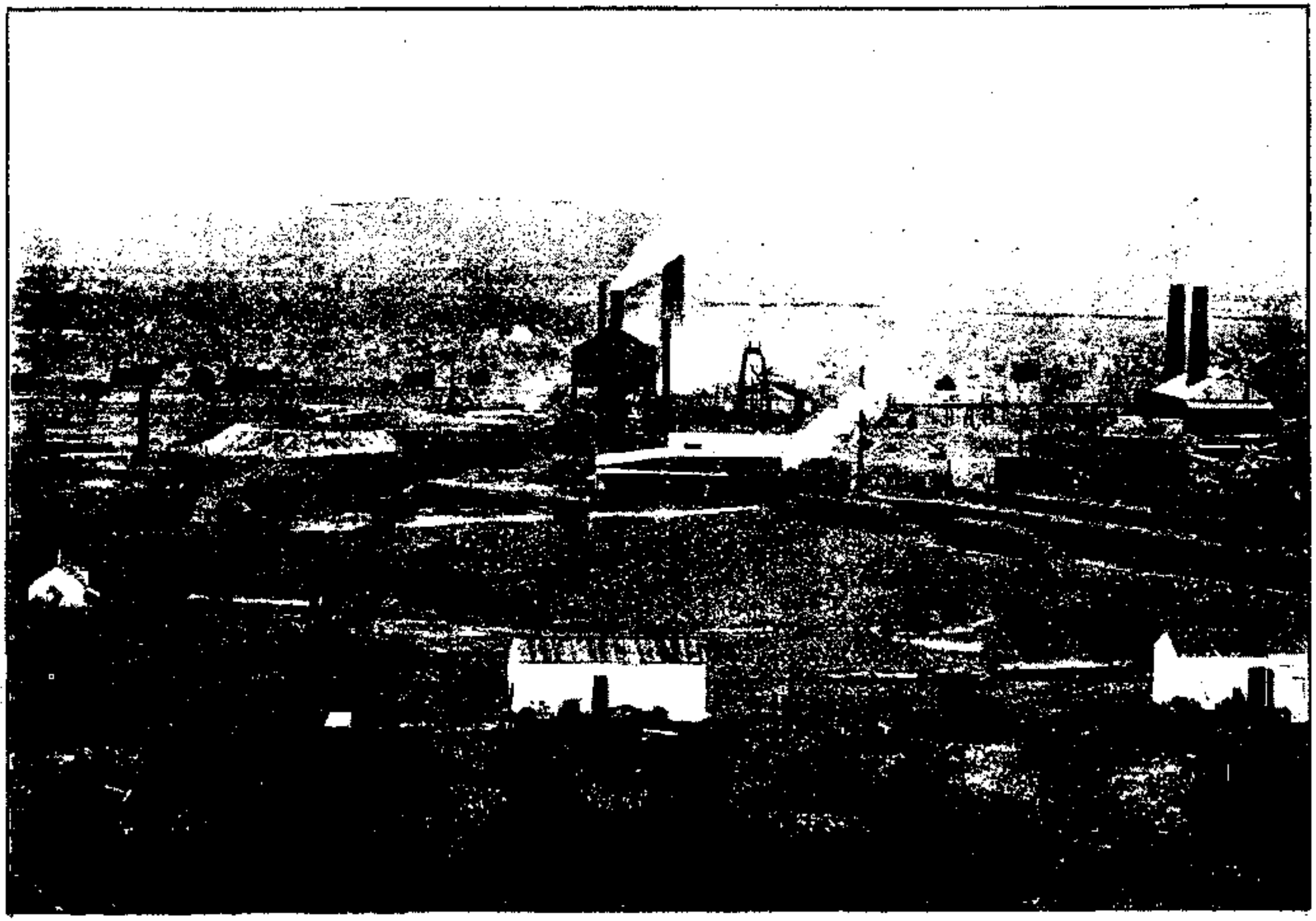
There is a mail receiver, but no telegraph office. The water supply, which is of fair quality, is obtained from a well, and costs 2s. 6d. per 100 gallons at the well.

Fresh meat is obtained from a butcher at Murrin, and averages for beef and mutton 1s. per lb. The townsite lies in hilly country, on a slope to the west. When the railway is opened, Anaconda will become the distributing point for the Yundamindera (18 miles east), Pendinnie, and Linden districts.

The town relies principally for support on the Murrin Copper Mines Ltd., formerly known as the Anaconda. Experienced miners aver that the hills for three miles round have surface traces of copper.

MURRIN COPPER MINES, LIMITED.

These mines are situate about four miles from Murrin Murrin and 16 miles fom Malcolm, the Government railway being within a few chains of the main workings.



MURRIN COPPER MINES, LIMITED.

The property consists of 205 acres. During past three and a-half years the mines have produced about 30,000 tons of ore, containing copper of a gross value of about £121,000, which is about half the total quantity of copper produced in Western Australia. The management is in the hands of Mr. Earle Huntley, who has been in charge of the properties for over three years

On the principal line of lode a main shaft has been sunk to a depth of nearly 400ft., and sinking is being continued. Levels here have been opened down to 300ft. and have revealed a very wide lode, running over 30ft. wide in places. This lode has also been opened up along the new faces by prospecting shafts for a length of about 1,200ft. The mines were last year purchased by a London company, when a vigorous policy of development was substituted, and a modern smelting plant erected. The process adopted was "Pyritic smelting," as the ore is a dense iron and copper pyrites and smelts readily with the addition of two per cent of coke. The mine is equipped throughout with high-pressure boilers, compound winding engines, and Cornish pumps, the mine making about 40,000 gallons of fresh water per day.

The smelting plant consists of a water jacket furnace with steel jackets), of a capacity of 150 tons per day, hot blast stoves, and a very powerful blowing engine for supplying blast to the furnace.

This is, we believe, the first blowing engine used in a smelting plant in Australia, and is a huge air compressor with compound steam engines, and designed to furnish an enormous volume of air at the pressure necessary for smelting:—the air cylinders being about 5ft. in diameter. This machine is found to work admirably. Reverberatories are used for producing copper—part of the produce is shipped as matte, and part as copper

The company complains that, although it is opening up, practically, a new industry for Western Australia, yet the rate on copper on the Government railways has been fixed at £2 17s. per ton, equal to about 1¼d. per mile per ton, or more than double the rate of bringing jarrah or local coal up to the goldfields, this notwithstanding the fact that the copper is all back loading.

The cost of living in Anaconda is moderate. Tinned meat is 10½d. per tin; flour, 10s. per 50lb. bag; potatoes, 2d. per lb.; jam (2lb. tins), 1s.; sugar, 3½d. per lb.; tea, from 1s. 6d. per lb There is a garden on the mine, where vegetables are grown, Cabbage costs 3d. per lb.; while fruit, which comes from the coast, costs:—Apples, 3s. to 1s. 6d. per doz., and oranges, 1s. 6d. per dozen.

LAND SETTLEMENT.

In conclusion, it may be of interest to give some particulars of the facilities for going on the land in Western Australia, and, although this book may be of interest to those whose sole idea is to learn about the goldfields, it is not improbable that, by chance, some may wish to know the terms on which they can acquire land whereon to make a home, while the head of the household works on the goldfields.

Guide to Land Selection in Western Australia.

LAND TENURES IN BRIEF.

Free Farms.—Min. area 10, max. 160 acres. £1 deposit; no other payments. Title earned by following improvements:—Fence one-fourth within 5 years, the whole within 7. Within 2 years erect house or do clearing worth £30, or prepare 2 acres of orchard or vineyard. Within 5 years clear and crop one-eighth of the area, or spend 30s. per acre on one-fourth of it. Within 7 years clear one-fourth or spend 60s. per acre on it. Personal residence required 6 months in each of first 5 years, or double improvements.

Residential C. P.—Min. area 100, max. 1,000 acres. Price, 6d per acre per annum for 20 years, payable half-yearly. Fence one-tenth within 2 years, all within 5. Spend 10s. per acre, less half-cost of exterior fence in 10 years. Residence on other C. P.'s within 20 years fulfils residence requirement.

Non-residential C.P.—Same min. and max. area and rent, but double above improvements.

Direct Payment C.P.—Min. area 100, max. 1,000 acres. Payment, 1s. per acre on application, balance in 4 equal quarterly instalments. Fence whole within 3 years. Within effect improvements worth 5s per acre.

Orchard C. P.—Min. area5, max. 50 acres. Payments, 3s. per acre on application, balance by 6 equal half-yearly instalments of 3s per acre. Fence within 3 years, and plant one-tenth area as vineyard, orchard, or vegetable garden.

Grazing Lands.—All applications subject to individual inspection and possible delay. Min. area 1,000, max. 5,000 acres Three hundred min. allowed where adjoining applicant's holding. Land valued according to quality, anywhere between 3s. 9d. and 10s. per acre. Payments, one-sixtieth of face value per acre half-yearly. Improvements:—Fence one-tenth in two years, all in five. Spend face value of land in improvements in 15 years, less half cost exterior fence if latter rabbit-proof. Pay half-cost survey in 10 half yearly instalments

Repurchased Lands.—Max. area 1,000 acres. Payments, 40 half-yearly instalments of £3 16s. 5d. for every £100 worth of land acquired Fence one-fourth in 2 years, all in 5 Clear one-tenth in 5 years. Within 10 years have improvements —including exterior fence—to show equal to face value of land. Personal residence a sine qua non.

Coach Fares and Freights.

Malcolm to Laverton, *via* Mount Morgan and Euro.

	Station.	Miles.	Parcels per lb.	Bicycles.	Fares. Single.	Fares. Return.
Leaves	Bummer's Creek	12	1d	£0 2 6	£0 5 0	£0 10 0
Malcolm	Murrin Murrin	22	1½d	0 5 0	0 12 6	1 5 0
6.30 a.m.	Mount Morgans	42	2d	0 7 6	1 10 0	3 0 0
Daily.	Hawke Nest	45	2½d	0 10 0	2 0 0	4 0 0
(Sunday's	Euro	62	3d	0 15 0	2 2 6	4 5 0
excepted).	Laverton	68	3d	0 15 0	2 2 6	4 5 0

Laverton to Burtville.

	Station.	Miles.	Parcels per lb.	Single.	Return.
Leaves	Euro	8	½d	0 3 0	0 5 6
Laverton	Childe Harold	14	1d	0 7 6	0 9 0
Tues. and	Edinborough				
Fridays	Castle	34	2d	0 15 0	1 3 0
11.30 a.m.	Mount Weld	39	2d	0 17 6	1 6 0
	Burtville	50	3d	1 0 0	1 13 6

Leaves Burtville on return, Wednesdays, and Saturdays, at 8 a.m. *via* Ida H.

Malcolm to Granites, *via* Murrin.

	Station.	Miles.	Parcels per lb.	Bicycles.	Single.	Return.
Leaves						
Malcolm	Anaconda	25	1½d	0 7 6	0 15 0	1 10 0
Wednesdays						
and	Granites	50	3d	0 15 0	1 10 0	3 0 0
Saturdays.						
6.30 a.m.						

Leaves Granites on return, Mondays and Thursdays.

Malcolm to Mertondale.

	Station.	Miles.	Parcels per lb.	Bicycles.	Single.	Return.
Leaves						
Malcolm	Black Chief	6	½d	0 2 6	0 4 0	0 8 0
Mondays,						
Wednesdays,	East Lyne	12	½d	0 3 6	0 5 0	0 10 0
and Fridays.						
6.30 a.m.	Mertondale	20	1d	0 5 0	0 10 0	1 0 0

Leaves Mertondale on return, Mondays, Wednesdays, and Fridays.

Leonora to Lawlers.

	Station.	Miles.	Parcels per lb.	Bicycles.	Single.	Return.
Leaves						
Leonora	Diorite	23	1d	0 7 6	0 12 6	1 5 0
Sundays,	Doyle's Well	43	1½d	0 12 6	1 10 0	3 0 0
Tuesdays,	Wildarra	75	2½d	0 15 0	1 10 0	5 0 0
and Thurs's.	(Poison Creek)					
7 a.m.	Lawlers	93	3d	0 17 6	2 17 6	5 15 0

Leaves Lawlers on Sundays, 6 a.m., Tuesday sand Thursdays, 5 p.m.

COOLGARDIE WATER SCHEME.

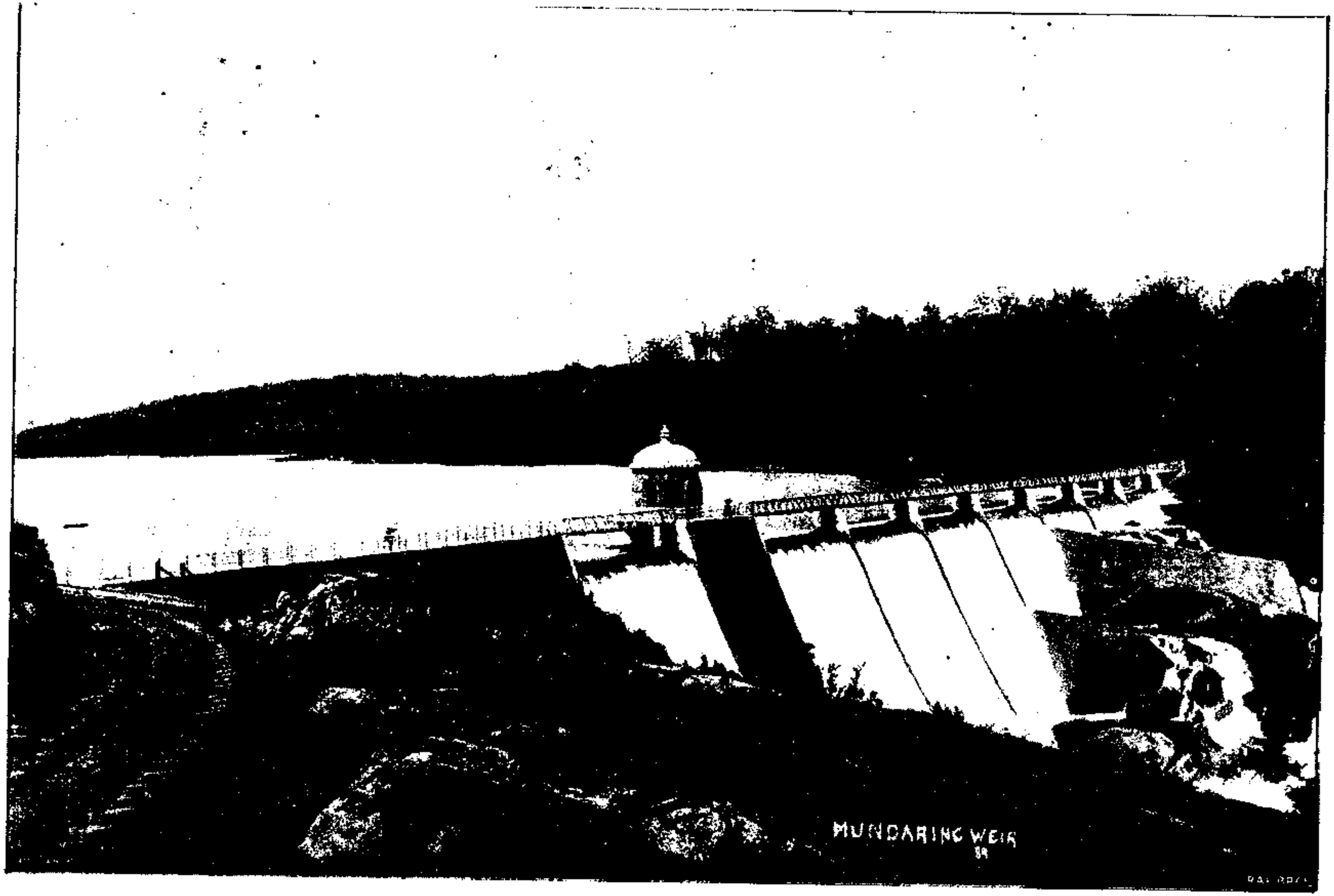
The lack of an adequate water supply for the Eastern Goldfields obtruded itself upon the notice of the Government in 1894, and the early part of 1895, because of the more than usually scanty rainfall, and it was felt something must be done. In 1894 a contractor, named John Maher, applied to the Minister for Mines for a right to take water from the tributaries of the Avon, at Northam, to erect reservoirs there and pump the water to Coolgardie, a distance of 290 miles. The Government promised support, and there the matter ended for the time being, but finally preliminary surveys were made, schemes were submitted by the late C. Y. O'Connor, C.M.G. M.I.C.E., Engineer-in-chief, and one which had the construction of a reservoir at Mundaring, on the Helena River, and thence pumping it to the summit of Mount Burges, near Coolgardie, at an estimated cost of £2,500,000 for 5,000,000 gallons per diem, was adopted. A bill was introduced in Parliament by Sir John Forrest, then Premier, in July, 1896, and was finally passed by both Houses on September 3, 1896.

The whole of the gigantic work was completed on January 26, 1903, at a cost of £2,670,000, and to-day the water is overflowing at the Mundaring Weir. The towns of Kalgoorlie and Coolgardie are reticulated, and householders may purchase good, clear water at 7s. per 1,000 gallons, as against 15s. per 100 gallons for condensed water less than two years ago. The benefit to the mines at Kalgoorlie is enormous, the Trust obtaining water at 5s. per 1,000 gallons.

The two illustrations show the site of the great Weir at Mundaring, with the work of construction in progress, and the Weir complete with the water overflowing—a monument of courage, enterprise, and engineering skill.

The principal particulars of the scheme as adopted (after consultation in London with a commission of the leading English engineers) are embodied in the following summary:—

Item.	Description.		Unit of Measure.	Amount.
1	Quantity of water required to be pumped per day of 24 hours		Gallons	5,600,000
2	Length of pipe main from storage reservoir to Kalgoorlie		Miles	358
3	Diameter of pipes to be laid (steel, locking-bar type)		Inches	30
4	Velocity of water per second		Feet	2·124
5	Net maximum lift from storage reservoir to main distributing reservoir	1,290		
	Plus allowance for immediate reservoirs	157	Feet	1,447
6	Head per mile allowed for friction (minimum)		Feet	3·76
7	Total head allowed for friction		Feet	1,208
8	Estimated gross head		Feet	2,655
9	Weight of water to be raised per diem ...		Tons	25,000
10	Work per diem		1,000 ft.-tons	66,375
11	Net effective power required		No. of H.P.	3,129
12	Power to be supplied P.H.P. of engines in work	3,712		
	Plus P.H.P. of engines in reserve	2,475	No. of H.P.	6,187



MUNDARING WEIR OVERFLOWING.

THE C. Y. O'CONNOR STORY

C. Y. O'Connor was born in Gravelmouth, County Meath, Ireland, in 1843. His education commenced at the Waterford Endowed School, from where he passed to Dublin University. When 16 years of age he became apprenticed to the Chief Engineer of the Waterford and Limerick Railways.

After serving his time he joined the firm of Messrs. Smith & Bagnell and increased his knowledge of railway construction. The future prospects in Ireland made him dissatisfied and when gold was discovered in New Zealand he made one of the most important decisions in his life — to emigrate.

C. Y. O'Connor arrived in New Zealand in 1865 and soon became Assistant Engineer to a road construction project in the South Island. The road led from Christchurch through the famous Otira Gorge in the Southern Alps to the scene of gold discoveries at Hokitika.

Five years later he was appointed engineer of the West Coast County and later became District Engineer for the whole Canterbury Province. Under his guidance many public works were accomplished including railways, harbours, bridges, roads and a number of reservoirs to supply the goldfields with much-needed water.

Charles Yelverton O'Connor became Under Secretary for Public Works in 1883 and held the position for seven years, becoming Marine Engineer for New Zealand in 1890, and as such was responsible for the overall supervision of marine and public works.

Falling gold prices and a shortage of money forced the Government to curtail some of their works expenditure and, following a disagreement with the Government O'Connor resigned to become Western Australia's Engineer-in-Chief of Public Works and Manager of Railways in 1891.

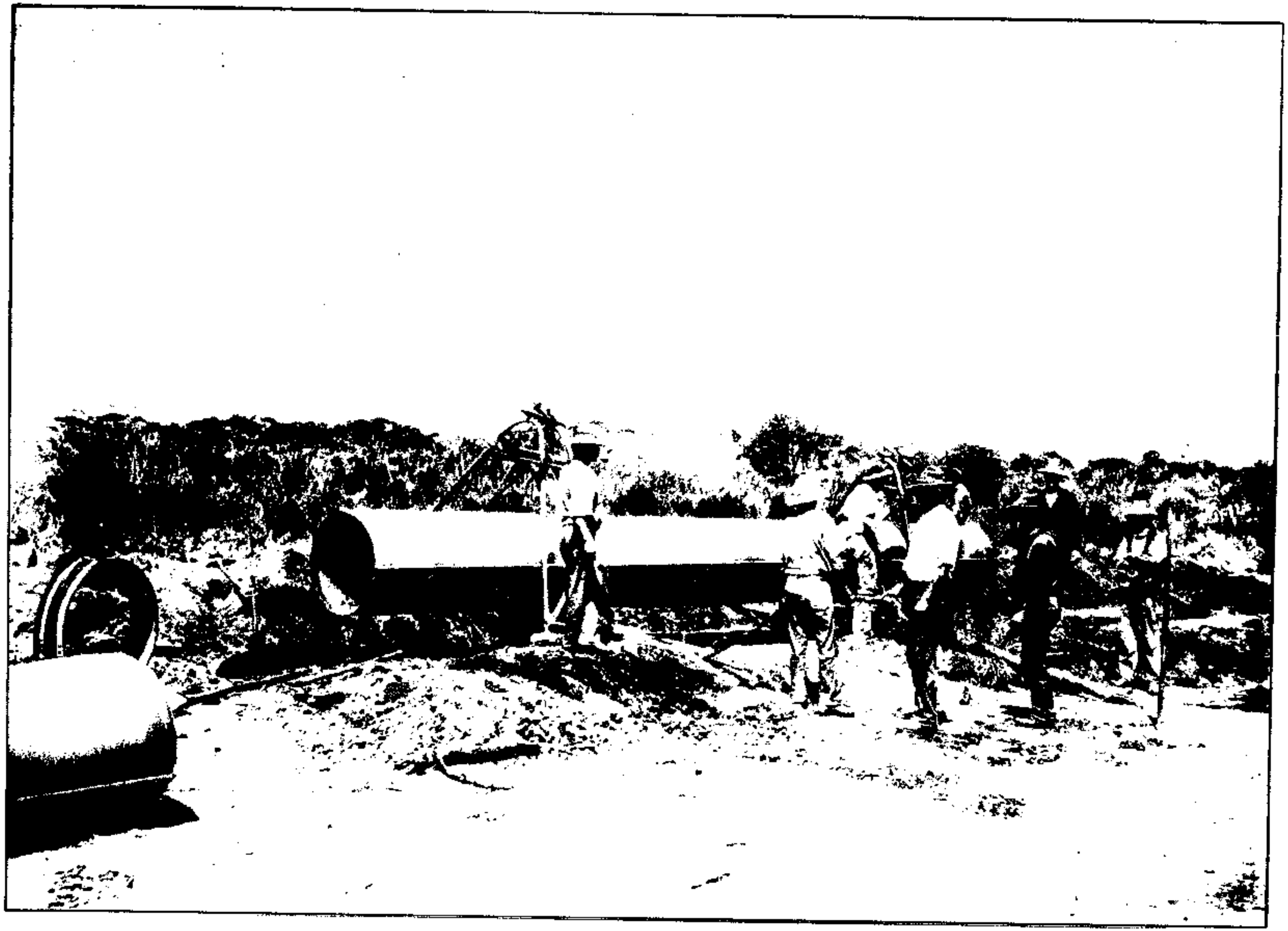
Luckily for Western Australia O'Connor's resignation came at a crucial time in the State's progress. To be able to obtain the services of this experienced and competent engineer was a boon for a small colony with such big problems.

At the request of the Premier Sir John Forrest, C. Y. O'Connor submitted proposals for a comprehensive water scheme for the goldfields. It envisaged the construction of a reservoir on the Helena River near Mundaring in the Darling Range, and eight pumping stations to convey five million gallons of water daily from the weir through 330 miles of cast-iron pipes to a reservoir to be constructed on Mt. Burges near Coolgardie. After a lengthy debate the Coolgardie Goldfields Water Supply Loan Act, 1896, was passed by Parliament to raise 2½ million pounds for the scheme.

In 1898 the final report was received from a Royal Commission in England, which was investigating the soundness of the water scheme. Tenders were called for the miles of pipe mains needed and for the pumping equipment. Work started on the excavations for Mundaring Weir and the railway line between Mundaring Station and the weir site was commenced.

By early 1902 work on the weir was nearing completion, and the laying and jointing of the pipes which had begun in March 1901, had slowly crept forward some 90 miles.

On the 31st March, 1902, a few weeks after O'Connor's death, pumping trials commenced at the No. 1 Pumping Station. Mr. C. Palmer faithfully and loyally carried on the work of his previous chief. Under his direction the laying of the remaining 260 miles of pipe progressed rapidly. Finally on 22nd December the water reached Coolgardie and by 16th January, 1903, it was ready to be supplied to the people of Kalgoorlie. The whole period of construction of the scheme had been less than five years.



PIPE LAYING IN 1903

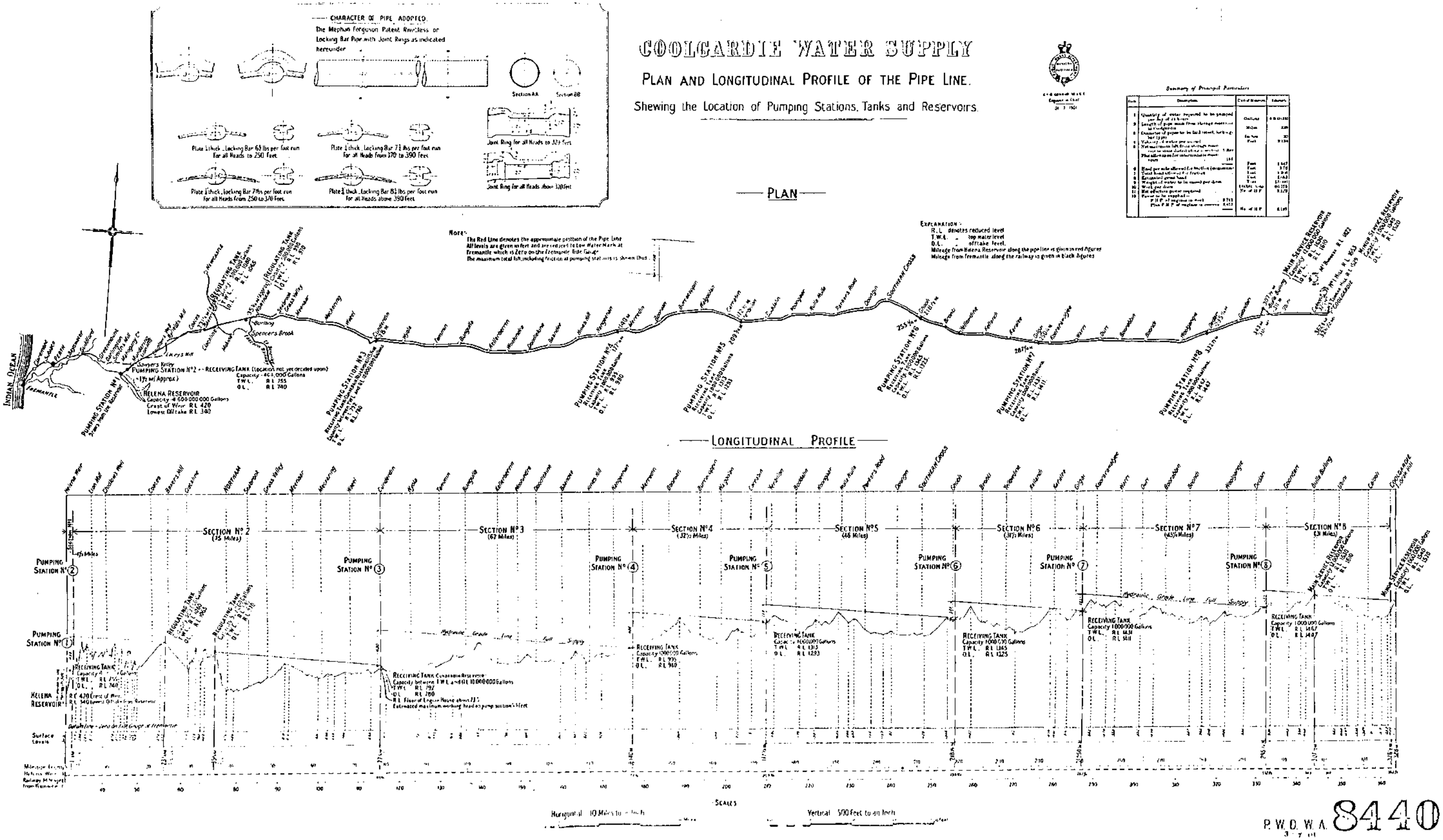
The actual time taken for the first pumping was ten months, but under normal working conditions the time was only about four weeks. Today modern electrically powered pumps have reduced this time for fourteen days.

The pumping machinery of the Coolgardie Water Supply scheme was officially started at Mundaring Weir on 22nd January, 1903, during an opening ceremony performed by Lady Forrest.

To commemorate some of the State's historic past and one of the greatest engineers of our time, the Western Australian Government decided in 1961, to establish an historic museum. Standing only a few yards from the overflow waters of Mundaring Weir, the old No. 1 Pumping Station of the Goldfields Water Supply was considered an ideal location for such a museum.

The O'Connor museum was opened by the Premier of Western Australia, the Hon. David Brand, M.L.A., on 25th March, 1961, and today stands as a tribute to the early pioneers of the State. Details of opening times of the Museum can be obtained by ringing the Public Relations Office of the Public Works Department on 322 0331.

LOCKING BAR PIPE RE-LAID 1972


COOLGARDIE WATER SUPPLY
PLAN AND LONGITUDINAL PROFILE OF THE PIPE LINE.
Shewing the Location of Pumping Stations, Tanks and Reservoirs.
CHARACTER OF PIPE ADOPTED.
The Mephan Ferguson Patent Rivetless or Locking Bar Pipe with Joint Rings as indicated hereunder
Section AA
Section BB
Joint Ring for all Heads to 320 Feet
Joint Ring for all Heads above 320 Feet
PLAN
LONGITUDINAL PROFILE
INDIAN OCEAN
FREMANTLE
PERTH
HELENA RESERVOIR
PUMPING STATION No 1
PUMPING STATION No 2
PUMPING STATION No 3
PUMPING STATION No 4
PUMPING STATION No 5
PUMPING STATION No 6
PUMPING STATION No 7
PUMPING STATION No 8
RECEIVING TANK
REGULATING TANK
MAIN SERVICE RESERVOIR
SOUTHERN CROSS
COOLGARDIE
SECTION No 2
SECTION No 3
SECTION No 4
SECTION No 5
SECTION No 6
SECTION No 7
SECTION No 8
Hydraulic Grade Line Full Supply
Surface Levels
SCALES
Horizontal 10 Miles to an Inch
Vertical 500 Feet to an Inch
P.W.D. W.A. 8440

The year is 1903.

You are about to embark on a train journey through country where, less than 10 years ago, men came by their thousands to seek a precious yellow metal—and the great West Australian Goldrush was on!

Even so, the towns that men built as they spread across the desolate Eastern Goldfields are already becoming forgotten . . .

. . . but now, in our State's 150th year, you have the opportunity with this book to travel those far-flung outposts again, and recapture the spirit of the Goldrush days.

It will be an educational, nostalgic trip for all those who want to remember those vital years in our State's development.

We wish you a pleasant journey—perhaps you too will catch the 'yellow fever' . . .

Published in Western Australia by Strickland Publications
Publishing Consultants: Carroll's Pty Ltd, 566 Hay St, Perth

Appendix 5

COMPLETED NOMINATION FORM AND CORRESPONDENCE

NATIONAL HISTORIC ENGINEERING LANDMARK

Nomination Form

National Engineering
Heritage Panel
Institution of Engineers, Australia
11 National Circuit
BARTON ACT 2600

Date: *March, 1986*

From: *Engineering Heritage Sub-Committee Western Australian Division*

(name of Division or Committee)

This is to nominate the following Work for designation as a National Historic Engineering Landmark:

(Name of Proposed Landmark) *Coolgardie Water Supply*

Located at *Hundaring Weir to Mt Charlotte Reservoir, Kalgoorlie*

State *Western Australia* Please furnish the address (and map grid reference if a fixed Work) *Hundaring Weir: 31° 58'S, 116° 10' E, Bulla Bulling Res. : 30° 0'S, 120° 51'E, Mt Charlotte : 30° 44'S, 121° 28,E.* The Work is owned by: *Water Authority of Western Australia.*

In support of this nomination the following information is provided:

1. Date of construction (or other significant date):

   Railway access to Hundaring Weir site, early 1898: Foundation excavation commenced in May 1898 and concreting in February 1900. Pipelaying commenced March 1901, First pumping April 1902. Water reached Kalgoorlie January 1903. Official opening January 26, 1903.

2. Name of key professional personnel associated with the Landmark:

C.Y. O'Connor C.M.G., M.I.C.E., Engineer-in-Chief 1891-1902
C.S.R. Palmer, M.I.C.E., " " " 1902-1905
Sir John Forrest, Premier of W.A. 1890-1901
J. Carruthers, M.I.C.E., Consulting Eng for W.A. in London, Member of the Commission of Inquiry
Dr. G.F. Deacon, M.I.C.E., Consulting Engineer, Member of the Commission of Inquiry
Prof. W.C. Unwin, M.I.C.E., Member of the Commission of Inquiry.
Messrs Mephan Ferguson & Hoskins, pipe manufacture
Messrs James Simpson & Co. Ltd, pumping plant

3. National engineering historic significance of the Landmark:

The proposal to pump 5 million gallons per diem a distance of 352 miles from a reservoir on the Helena River at Mundaring, against a static head of 1290 feet, was courageous for the period 1896 to 1902.

The use of thin-walled steel pipes using the locking bar method of construction was unparalleled for the length of pipeline involved.

4. Comparable or similar Works (a) in Australia. (b) Overseas.

It is believed that nowhere else in the world and certainly nowhere else in Australia, was there a scheme which carried water in the same quantity, the same distance and to the same altitude.

At the time of construction the Mundaring Weir with a height of 100 feet was the highest overflow weir in the Southern hemisphere.

The Commission of Inquiry initially rejected the locking bar system as unproven on large scale construction. However, before tenders for supply of pipes were received 10 miles of 25.5 inch diameter locking bar main had been successfully laid in South Australia.

5. Unique features or characteristics which set this proposed Landmark apart from other engineering Works, including those in 4 above:

The whole period of construction was less than five years, although it was necessary to import all material for construction of the pipes, cement, valves and specials, lead for jointing, pumping machinery, the ironwork in the weir, and much other material.

6. Contribution which this Work has made towards the development of: (1) the engineering profession and/or (2) the nation:

The pipeline construction developed the use of thin-walled steel pipes using the locking bar construction for water supply to remote areas typical of Australian conditions.

A reliable water supply for the mining settlements and the railway ensured permanent settlement on the arid eastern goldfields and the viability of the gold mining industry there. This was the first great boost in the development of Western Australia.

7. In further support of this nomination the following documentation is submitted: (please list all enclosed documents, photographs and supporting historical evidence).

A fully documented submission with photographs is currently being prepared and will follow shortly.

8. <u>For completion by Committee or body (other than a Division) making the Submission.</u> A copy of this Submission has been forwarded to the Secretary of the <u>N/A</u> Division at ______________________.

We have discussed this nomination with the owner of the Work. The owner has indicated that *<u>The Water Authority of Western Australia</u>*

(include statement regarding owner's attitude)

will support the nomination, contribute to preparation of a fully documented submission and take an active role in any subsequent marking ceremony.

If this nomination is approved for designation as a National Historic Engineering Landmark by the Institution of Engineers, Australia, we understand that the Division or Committee will be expected to take a major responsibility in the development of a suitable presentation event at which the national plaque would be publicly presented.

T.J.B. Swanson

Chairman of Nominating Body

Secretary of Nominating Body

This form may be reproduced either by electrostatic copying or by retyping. If possible, please submit eight (8) copies of all materials relating to the nomination. If more space is required to provide full response to any of the above, please attach additional pages.

NOTE: With enclosed additional documentation please also include 200 x 250 mm black and white photos which depict the work and can be used for publicity purposes. Also requested are 35 mm colour slides which can be used for a slide presentation.

(3343D)

WATER AUTHORITY
of Western Australia

620 NEWCASTLE STREET
LEEDERVILLE W A
Postal Address P O Box 100 Leederville
Western Australia 6007
Telephone (09) 420 2420 Telex AA 95140

Your Ref
Our Ref E 894, Copy F 11686
Enquiries F Watson
Tele Direct 420 2508

Secretary
Engineering Heritage Sub-Committee
The Institution of Engineers,
Australia, W.A. Division
712 Murray Street
WEST PERTH W.A. 6005

Dear Mr Sullivan

AUSTRALIAN ENGINEERING MARKER PROGRAMME

At its meeting of April 10, 1986 the Board endorsed a proposal by the Western Australia Division of The Institution of Engineers, Australia to nominate the Coolgardie Water Supply Scheme 1898-1903 for marking by the Institution as a national engineering landmark. The Board resolved that the Authority would co-operate in the preparation of the final submission for the nomination and that, if the nomination is successful, the Authority would organise and contribute to a marking ceremony.

The Manager, Water Resource Planning Branch should be contacted for assistance in preparation of the final submission.

The Manager, Public Affairs Branch will be responsible for arrangements for any appropriate marking ceremony in due course.

Yours sincerely

Frank E. Watson

Frank E. Watson
EXECUTIVE ENGINEER, OPERATIONS
for MANAGING DIRECTOR

22 May, 1986 FEW:LH

c.c. Manager, Water Resource Planning Branch
Manager, Public Affairs Branch

4527F.